TECHNIQUES FOR SULFUR SURFACE BONDING FOR LOW COST HOUSING

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PROLOGUE

Improving the quality and lowering the cost of low-income housing is a challenge facing all parts of today's world. Recognizing the urgency of this situation, the U. S. Agency for International Development has initiated a number of programs to alleviate this situation and to assist in providing better housing at less cost for people throughout the world.

As a part of its long-range program, AID assigned Southwest Research Institute the task of developing innovative techniques for surface bonding in public housing.

The program began in early 1974 in Colombia. Since that time, prototype houses have been constructed in Bogotá and in Cartagena, and discussions are underway to implement these initial efforts on a much larger scale.

It is hoped that this handbook will serve as a guide to those individuals and organizations who wish to utilize these techniques in their own cities and countries. None of the techniques described nor materials used are proprietary or patented; no organization or country has an exclusive claim to their rights.

The Southwest Research Institute team is grateful for the efforts and contributions of many individuals and organizations in behalf of the program. In particular, SwRI would like to extend its thanks to the staff of the USAID Mission in Bogotá -- to William Ellis and to Alfonso Corredor; to Dr. Efraim Otera, Dra. Lee de Gouffray and the staff of COLCIENCIAS in Colombia; and to the Instituto de Credito Territorial, whose counsel, advice and assistance made the program a reality. At ICT, the efforts and enthusiasm of Alberto Vásquez, Pedro Javier Soto, Eduardo Parra, Darío Valencia, Rafael Valdiri and Ronald Moreno in Bogotá and Reynaldo Martínez, Edgardo Martínez and Gustavo Armador in Cartagena made the program not only a reality but a pleasure.

Henry Arnold, Director of the Office of Science and Technology of AID in Washington and Merrill Conitz, project leader of the program for AID, contributed much insight and valuable guidance as the program evolved. We are grateful for their continuing support and assistance.

SwRI is also appreciative of the efforts of Olga Arango de Albán in behalf of the program and for her excellent translation of the handbook.

We of Southwest Research Institute are honored and privileged to have worked with these individuals. We hope our efforts have contributed in some way to the public housing program of Colombia.

David Black
San Antonio, Texas
June, 1975

Sulfur Surface Bonding Project

Foreword

"Reasonable shelter," according to the Agency for International Development's policy determination on shelter,* "is an essential element in the improvement in the quality of life for the poorest majority." At the same time, it is recognized that the poorest segment of the population, which in most developing countries constitutes the majority, has inadequate shelter. It is desirable, therefore, that development assistance programs recognize this need and direct an appropriate amount of their efforts toward the shelter sector.

What is meant by an "appropriate amount" must be viewed in light of the many critical demands placed on the decreasing amount of development assistance funds available. The Agency's financial and personnel resources have been declining in recent years, while at the same time, inflation combined with the rapidly rising cost of energy, has seriously diminished the impact of development assistance efforts. It therefore has become necessary to establish priorities which direct these limited resources available toward mitigating the most critical problems of the poorest people.

By Congressional mandate, AID is focusing its development assistance program in the important areas of "Food and Nutrition," "Population Planning and Health," and "Education and Human Resources Development." An additional category of lesser priority is called "Selected Development Problems," and includes selected aspects of urban development, industrial

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* See Policy Determination 55, (Revised) October 22, 1974, Shelter Program Objectives.

development, science and technology, and infrastructure development. The shelter and public works sectors fall under this category.

AID's goal in the shelter sector is to assist developing countries in analyzing their own housing requirements, planning and developing policies to meet these requirements, and establishing the institutional, technological, and financial capacity required to provide reasonable shelter for all levels of society, but particularly for the poorest majority. AID has concentrated on provision guarantees on housing loans through the Housing Guarantee Authority to increase capital flow, as the availability of capital is the greatest single limiting factor in the improvement of developing country housing.

In addition to direct financial support through guarantee, grant and loan mechanisms, AID assists developing countries in meeting the minimum shelter requirements of poor families by specific technical services, such as;

(1) Advising on the establishment of housing standards that assure the minimum requirement of health and safety and enable the construction of shelters that the poor can afford.

(2) Supporting the "sites and services" approach, which provides poor families with homesites in new tracts of urbanized land with basic supporting infrastructure services on which to build a shelter with their own labor.

(3) Providing technical assistance in order to develop viable institutions to mobilize savings and provide small credits to families for financing acquisition of their homesites, purchase of building materials, or construction of a core house.

(4) Assisting the developing countries to adapt new housing materials and construction technology to reduce costs or improve the performance of low-cost housing, using U.S. research and technical capacity that is applicable to LDCs.

In order to carry out a viable shelter strategy, there must be strong and sustained efforts in research and institution building which draw upon the best talent available in the housing sector. The magnitude of the problem is illustrated by the fact that even industrialized countries, with their relatively greater financial and technical resources have not been able to solve all of their own housing problems. There is need not only for more research in the development of low cost shelters, but also in the adaptation of advances in developed country housing technology to meet the unique needs and situations of the developing countries.

AID's research and development program on technology adaptation for improved low cost housing in developing countries is managed by the Office of Science and Technology and Office of Housing with the cooperation of the Office of Engineering. The program includes limited activities in; (1) housing policy and institutional development, (2) materials technology with emphasis on substitution and adaptation, and (3) housing technology development and adaptation.

The Sulfur Surface Bonding Project was developed to help meet the objectives of materials substitution and technology adaptation. Sulfur has certain physical properties that make it an excellent surface coating and bonding material when melted and combined with various chemical additives and reinforcement fibers. Where sulfur is more readily available and less costly than cement, it becomes an economically beneficial subsitute in block wall construction.

Several years ago the Southwest Research Institute constructed an experimental building on its San Antonio Campus using the sulfur bonding technique. The experimental work done on this building and in subsequent experiments on surface bonding with cement as well as sulfur has resulted in a technology that has wide potential applications in building construction.

AID recognized this as a technique that would have application in low cost housing in developing countries. It was also known that sulfur is cheap and abundant in many parts of the world and thus had potential application in low cost house construction. The substitute material combined with an adapted technology, therefore, appeared to be an attractive package for developing countries. In addition to some supplemental technical data on its application to low cost house construction, AID and the Southwest Research Institute needed additional data on its economic advantages and its social acceptability. Accordingly Southwest Research Institute was awarded a contract to construct four test houses in each of three countries and to collect and evaluate the needed data. The data collected and experience gained during this project will provide a basis for introducing the sulfur technique in other developing countries.

The Sulfur Bonding Project is one of several examples of how AID, with limited resources, is matching relevant aspects of U.S. science and technology with an important need of developing countries.

Surface Bonding Technique for Housing

Colombia, South America

Architectural Considerations

by

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January, 1975

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SURFACE BONDING TECHNIQUE

Chapter: Architectural Considerations

Introduction

The great technological advances in recent decades have made it feasible to perfect an exterior and interior wall system utilizing the basic load-bearing block and a joint or surface coating which will produce a motarless wall element equal or superior in performance to the contemporary block-mortar component system; and in particular applications evidicing an economic advantage. Such applications may be found in residential architecture where certain configuration, density, simplicity, and habitability level are extant, and where the burden of critcal housing relief cries for any useful system utilizing local or available materials, supporting present or higher levels of employment, and by its economy affords more housing within a set time and cost reference. These conditions of dire need for low cost housing in Colombia appear to furnish a favorable background for demonstration of the surface-bonding technique in the residential category.

Residential Development and Siting

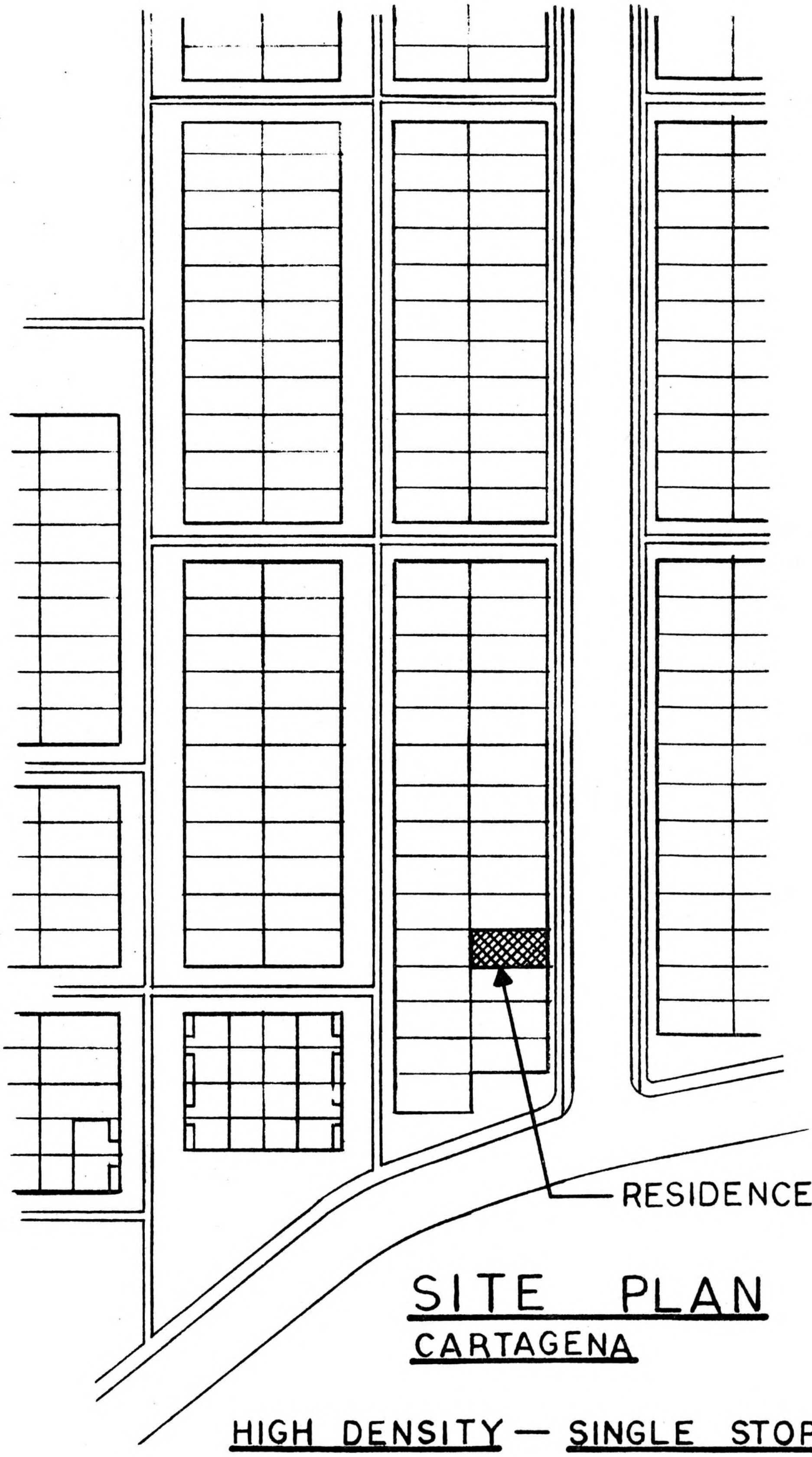
The residential category is selected within the framework of the low income segment of population, wherein lies the tremendous need for housing. This income group has the earning capacity to acquire a residence ranging from 35,000 to 45,000 pesos. The provisions for housing at this low cost requires a high density development complex, where a maximum of residences are positioned within a workable siting disposition: See Figure 1.

Each house is constructed separately and individually, but are situated adjacent to one another, back to back, forming double row-housing. There is no single common wall between units but each residence has its own exterior walls. The structure of each house is independent. The structures are single story, and contain a gross floor area varying from $68.4M^2$ at Cartagena to $55.5M^2$ at Bogota. The lot size at Cartagena, approximately $73.8M^2$ is practically fully covered by the housing unit, by including a larger patio within the unit itself. Whereas in Bogota, the units are set back on the lot a considerable distance, with no secondary patio. The lot size at Bogota is $72.0M^2$.

Design and Space Use

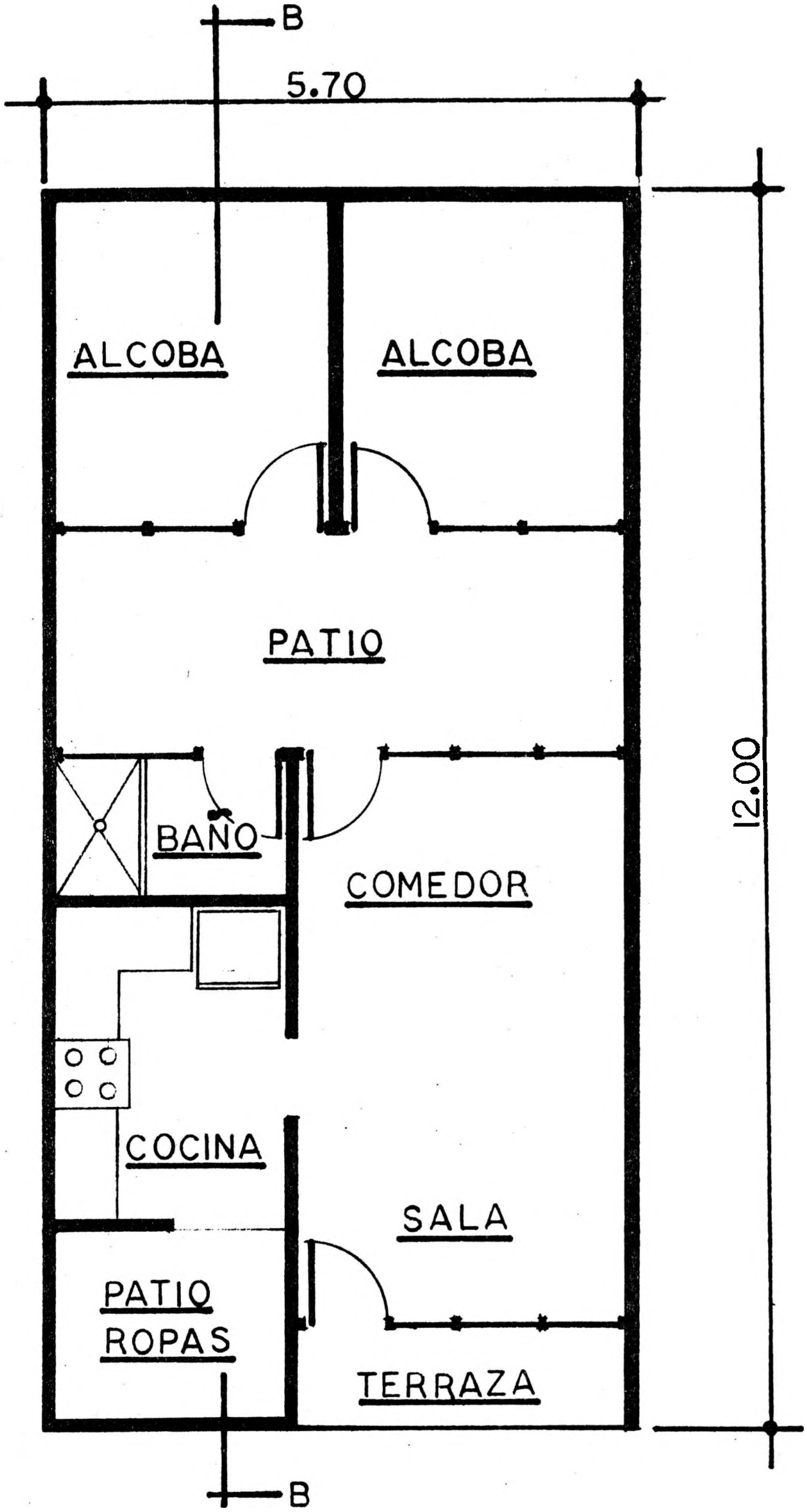
The residence of this size accomodates a family of two adults with two to four children. It is self contained as to function area needs, and provides the following spaces of sizes as indicated below: (See Figures 2 and 3).

	Area (M^2) Net			
Space	Cartagena		Bogota	
° Sala/Comedor	(5.50 x 3.10)	17.05	(4.85 x 2.80)	13.58
° Patio Ropas	(2.30 x 1.80)	4.14	(6.0 x 2.45)	14.70
° Cocina	(3.20 x 2.30)	7.36	(1.7 x 2.9)	4.93



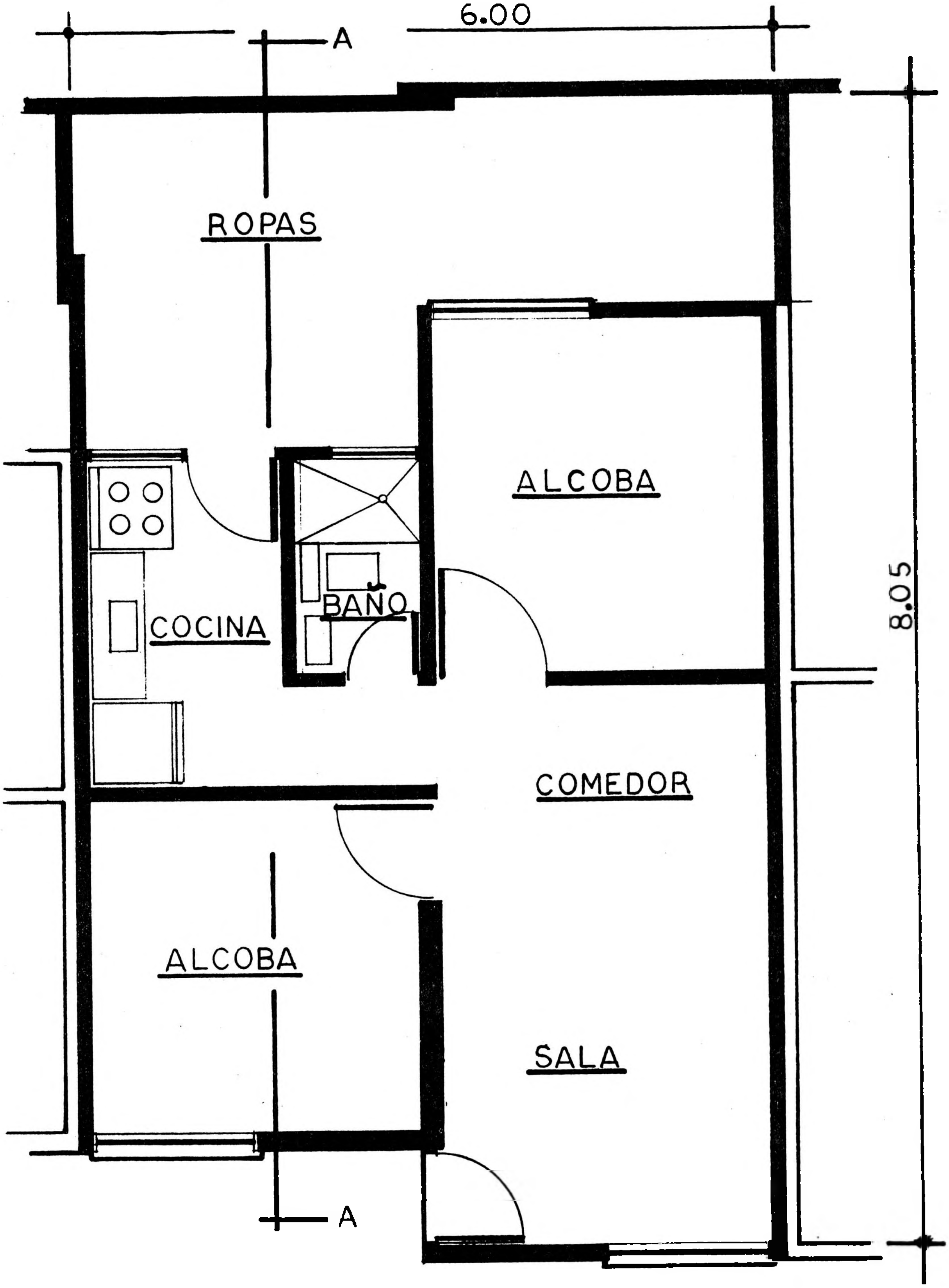
SITE PLAN
CARTAGENA

HIGH DENSITY — SINGLE STORY HOUSING



PLANTA GENERAL

CARTAGENA



PLANTA TIPO ESC. 1: 50

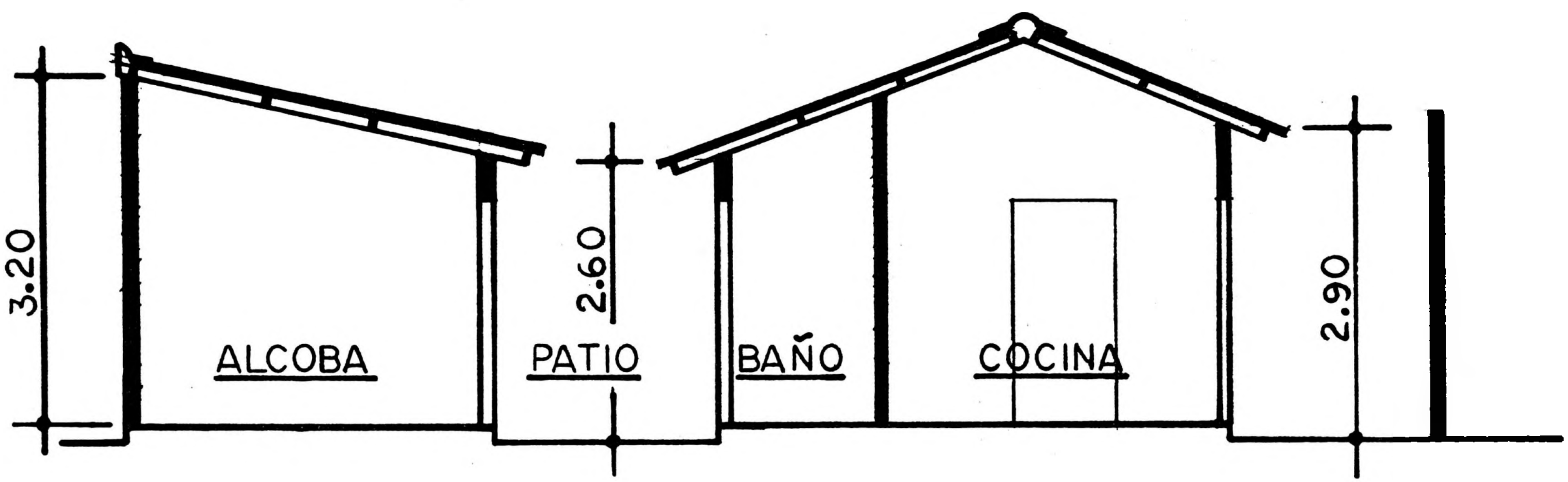
BOGOTA

Design and Space Use (cont'd)

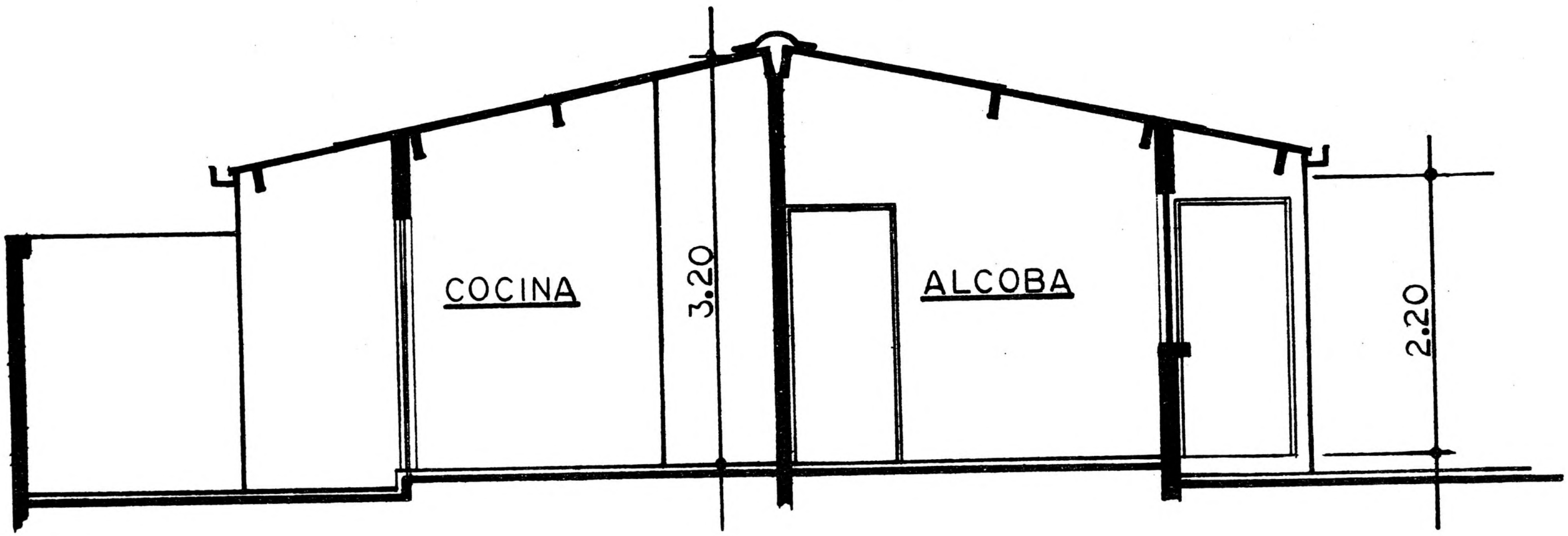
Space	Area (M^2) Net Cartagena		Bogota	
° Baño	(1.30 x 2.30)	2.99	(1.2 x 1.95)	2.34
° Patio	(5.50 x 2.10)	11.55		
° 2 Alcobas	2x (3.00 x 2.70)	16.2	2x (2.9 x 2.8)	16.24
° Terraza	(3.10) x 2.20)	6.82		
		66.11		51.79

At Cartagena the terraza at the entry, the patio ropas and the patio separating the main living spaces from the sleeping area are not roofed. The roof is double pitched over the living area and a single pitch over the sleeping spaces. The roofed portions of the house cover a net floor area of 43.6M^2 or 65% of the total area. The inside clear height varies from a low at the eaves of 2.40M to a high at the ridge of 3.20M. (See Figure 4).

At Bogota there is a double pitched roof over the living spaces with an open Ropas. The living spaces cover a net floor area of 29.0M^2 or 66% of the total area of the residence. The clear height at the eaves and ridge is approximately the same as Cartagena. (See Figure 5) The fenestration is provided to spaces from the street elevation and to spaces off the patios and ropas. At Cartagena with its tropical climate, no glazing is needed. All fenestrations, of course, are within walls that are non-load bearing.



CORTE B-B



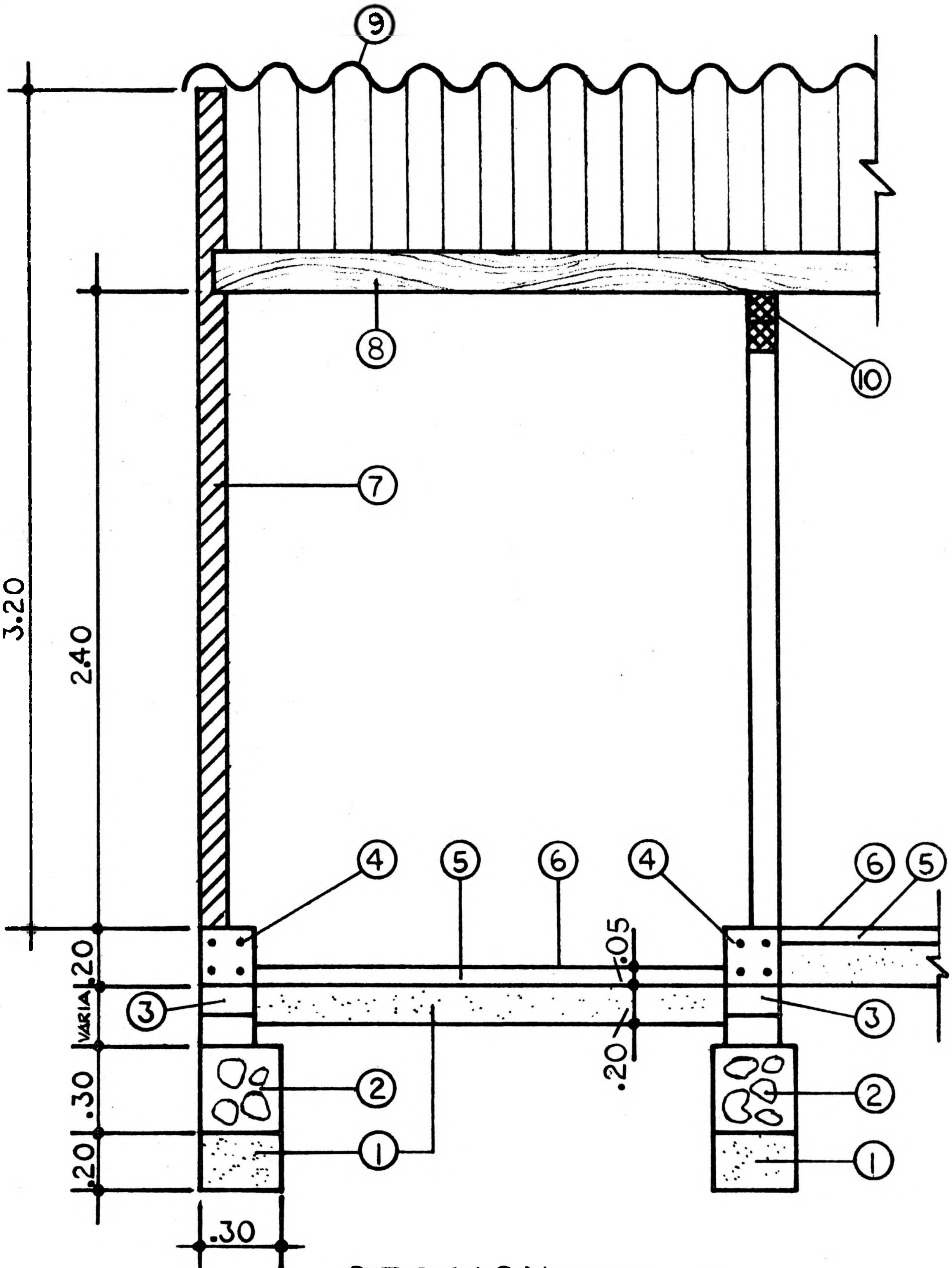
CORTE A–A ESC. 1: 50

Material Systems

The single story residential structural system is extremely simple. The three part system comprises first, the foundation, a continuous footing and grade beam under all walls; secondly masonry block, load bearing wall elements as both exterior common walls running the depth of the house with an additional intermediate parallel interior masonry wall forming the interior partitioning which segments the spacial elements of the plan; and third, the roof beams supporting the roofing and bearing on the three masonry wall elements. Thus, the roof loads supported by the roof beams are transmitted at three points each to the masonry walls. Thence to the footings bearing on compacted fill below grade.

The roof loads imparted to the masonry wall elements through the beams are in the magnitude of approximetely 60 Kg. as a point load. This, when distributed through the bearing walls is distributed throughout as an equivalent uniform load of 40 Kg. per meter length of wall. The total load per wall including the weight of the masonry wall element is 2700 Kg, or approximately 450 Kg. per meter length of wall at the footing.

The material components comprising the building elements are indigenous to the locale and are selected for their availability, performance, and economy. Figure 6, shows a partial section through the building illustrating the typical interior and exterior wall elements, and by reference numbers identifies the various component materials used in the residential



SECCION

construction, as itemized below:

1. Zahorra Compactada En Capas De 0.10

2. Cimiento Concreto Ciclopeo 2.000 psi

3. Sobrecimiento En Ladrillo

4. Sobrecimiento Concreto Reforzado Longitudinalmente 4 Ø 3/8" + Est. Ø 1/4" c/0.25 mts.

5. Placa Concreto Timple 2.000 psi

6. Piso En Cemento Afinado

7. Masonry blocks; typical nominal size .10 x .20 x .40 (actual .95 x .19 x .39) and in some instances nominal .20 x .20 x .40.

8. Roof Beams: Wood, 3" x 3" or 2" x 4"

9. Roofing: Corrugated cement asbestos 3/8" thickness; Sheets 1.0 x 1.5M

10. Lintels: Masonry block over openings in masonry walls

Since the surface bonding technique utilizes merely a surface or joint coating, with motarless joints, the design and construction must accomodate this feature dimensionally. The face dimensions of the typical masonry block are approximately .19 x .39. When used with .01 mortar joints the modular dimension is then .20 x .40 center to center of joint. However, with the surface bond technique, there is no mortar to make up this one cm joint thickness so that when stacked the block must be shimmed with wooden pegs, if not truly rectangular; and the vertical dimensions at openings, at roofs and at beams or lintels must be adjusted accordingly. For instance, a typical wall of mortared joints of 2.40 height will have 12 coures of block (.10 x.20 x .40). But a surface bonded mortarless wall will have 13 coureses, and its actual height will be 2.47. Similiarly, the door and window frames if precut or precast must adjust dimensionally to the new opening sizes. A 2.00 door would be either 1.90, ten courses high, or 2.09, eleven courses; and a sash opening of 1.00 would change to .95, five courses high. The horizontal dimensions may be accomodated readily by cutting the appropriate blocks.

Utilities

Provision for utilities within the residential unit is relatively simple. The sanitary piping system is installed below grade in the compacted soil before the concrete floor is poured. Three inch diameter drains collect at a concrete distribution box which connects to a four inch house sewer that runs to the street sewer main. The water line from the underground main runs through the exterior wall at the street elevation above the floor along the "wet" or plumbing side of the house. It services the Ropas, Cocina, and Baño spaces.

The electrical service enters the house overhead to a distribution box on the wall of the Sala. From the box through conduit which is notched into the masonry block walls the power is distributed to the various spaces. Each space is accorded a lighting box and outlet and a convenience outlet at the wall.

The weather conditions at Cartagena and Bogota are such that no heating is needed, and the economic level of the occupants precludes any air conditioning. So that there are no mechanical services installed in the residence.

Construction Sequence

When the building site is prepared, the footings of block are placed and mortared to achieve the desired elevation for the grade beam. This continuous member, running under all walls of the housing unit is formed and steel reinforcement placed, and concrete is poured to the screeded level for the finish floor elevation. Once the concrete grade beams have set and the underground house sewer piping is placed, the concrete floor slab is poured over compacted fill base to the desired finish floor elevation. This completes the foundation phase of the construction following the finish troweling of the concrete surface.

When the concrete has cured a sufficient length of time the wall element system proceeds. This system comprises masonry block units, and a liquid molten sulphur/asbestos fiber or fiberglas compound applied either to the joints or to the entire block surface by brush or spray. The first course of blocks are placed over the grade beam and an amount of the molten (heated) sulphur/compound is poured into the block cells or cavity to anchor the wall element to the foundation. Sand may be used to pond the molten sulphur at the joint of the block and the grade beam/floor slab until set. The next three or four courses of block are then stacked dry, leveling and plumbing each course with wood pegs. When four or five courses are placed, the sulphur/asbestos fiber compound is brushed along the joints, vertical and horizontal, on both sides of the wall. The joint lap coverage is approximately .05 or .025 on the surface of each block. The compond solidifies in less than a minute forming an immediate effective tensile bond. The wood pegs are removed as soon as the compound begins to harden.

When the lintel height over openings in the walls is reached, the lintels which are made on the ground are lifted into place and that course stacked and joints brushed in the normal manner. Two methods are used for lintel preparation. One is to impregnate the blocks in molten sulphur for 30 minutes, then butt end to end the number required for the lintel and paint the joints with the sulphur formulation. The other is to fill the block cavity with the sulphur formulation and butt the blocks end to end painting the joints.

When the eave height is reached the blocks at the walls paralled to the roof slope are cut back and stacked as gable ends to form the line of the roof slope. Then the final course acting as a rake from eave to ridge sloping with the roof, is placed and the joints painted with the sulphur formulation. Where the roof beams are to be located the block is notched and the beams let in, then painted at the juncture. The cement-asbestos roofing sheets are then tied by wire to the beams. At Cartagena, where poor soil conditions prevail, in the traditional house a beam/lintel at the tenth course was poured in-place. This was used to tie all walls together, both exterior and interior. However, utilizing the surface bonding technique, these lintels were eliminated since this method imparts continuous tensile strength throughout the wall.

In the placement of utilities, the sewer and piping systems as mentioned previously were set at the foundation phase of construction. The electrical boxes and conduit are notched into the block walls after they are set and the house has been roofed.

System Performance

The structural performance of the surface-bonded wall system compared with that of the traditional masonry wall has been evaluated in the United States by tests conducted by the Corps of Engineers and reported in their Technical Report No. 4-43. Reports of similar comparison testing on Colombian materials by the University of the Andes have not been received as yet. Therefore, in the interim, the results of the Corps of Engineers are shown below using concrete blocks comprising gravel aggregate:

Test	Mortar Joint	2" Strip No. Coats	Sulphur/Fiber Glass Joint
Flexural Strength (psi)	Failed of own weight	1	34
		2	121
Bond Strength (psi) (1)	8	1	76
		2	235

Test	Mortar Joint	2" Strip No. Coats	Sulphur/Fiber Glass Joint
Racking [2] Load to failure (pounds)	11,500		17,000

Test standards are (1) ASTM E149-59T
(2) ASTM E72-61

Paint adhers readily to the surface of the surface bonded wall system as does, stucco, plaster or cement finish. The paint endurance tests conducted by the Corps of Engineers according to the ASTM standard 42-57 showed no deterioration.

During construction there is a distinct odor present (sulphur) when applying the molten formulation to the block joints. However, it was not offensive to construction personnel. This odor following completion of the wall elements lingers for a period of not more than a week and is then dissipated.

The permanence of the surface bonded system over a period of time is evidenced by the excellent performance of a building (5.48 x 9.14) constructed at Southwest Research Institute in 1963. The system used cinder concrete blocks fourteen courses high where the entire surface both sides was brushed with the molten sulphur/glass fiber formulation. A wood roof truss supports a corrugated cement asbestos roofing. Through eleven years of extreme temperature changes from 15^{o}F in winter to 100^{o}F in summer the condition of the building shows no cracking, spalling, or deterioration in any manner whatsoever.

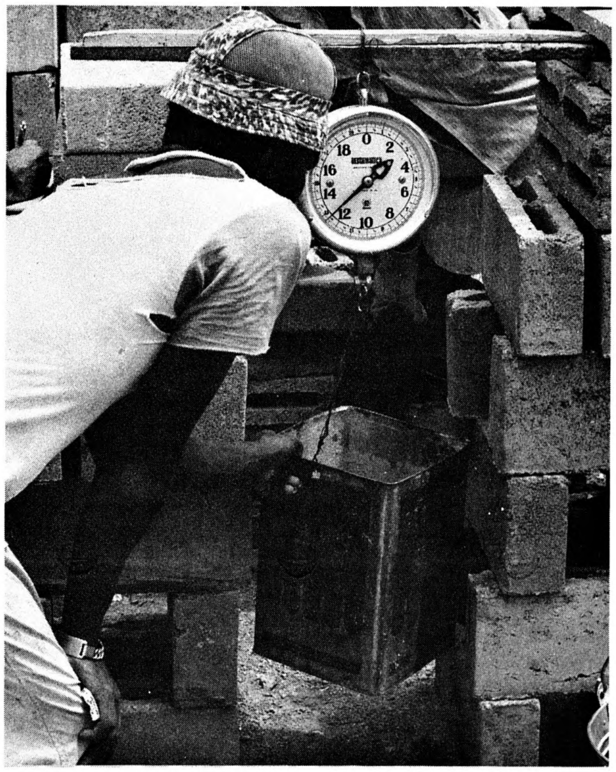


Figure 7. Weighing Compounds for the Formulation

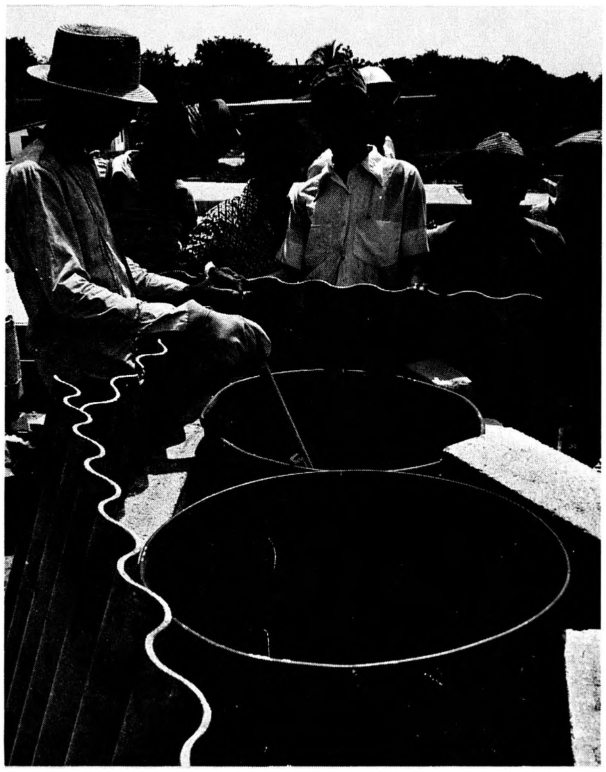


Figure 8. Mixing the Formulation in
55 Gallon Drums on Site

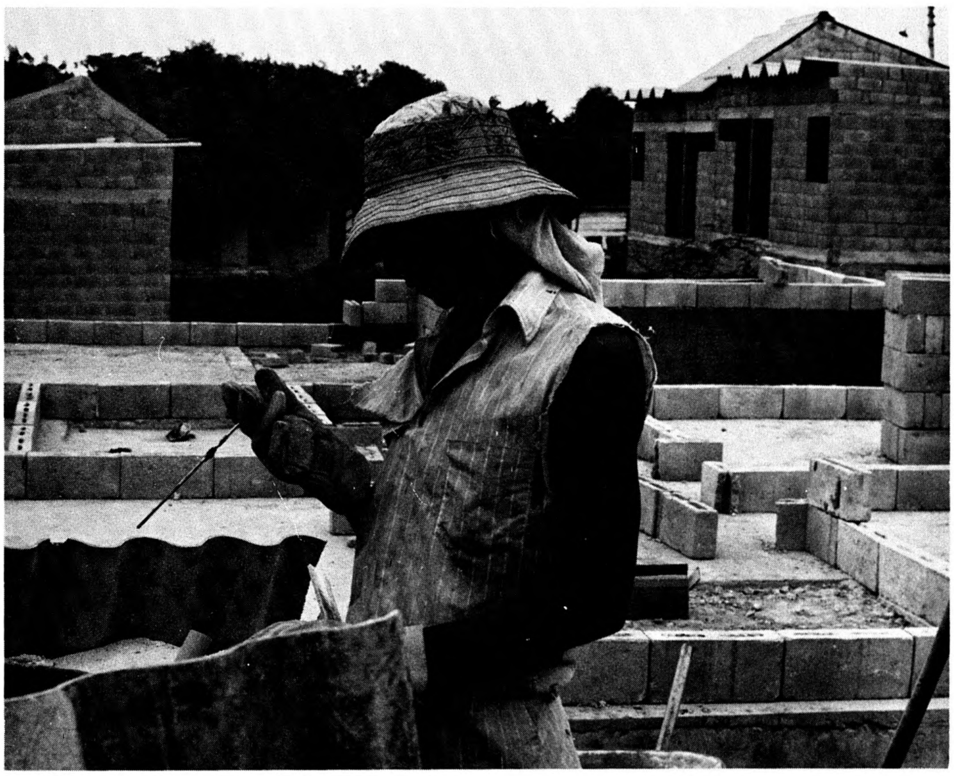


Figure 9. The Temperature Must be Carefully Regulated at 150°C.

Figure 10. Bonding the First Row of Blocks to the Slab With the Formulation

Figure 11. Wooden Wedges Were Used to Level Irregular Blocks

Figure 12. Several Rows of Blocks Were Stacked and Then Painted With the Formulation

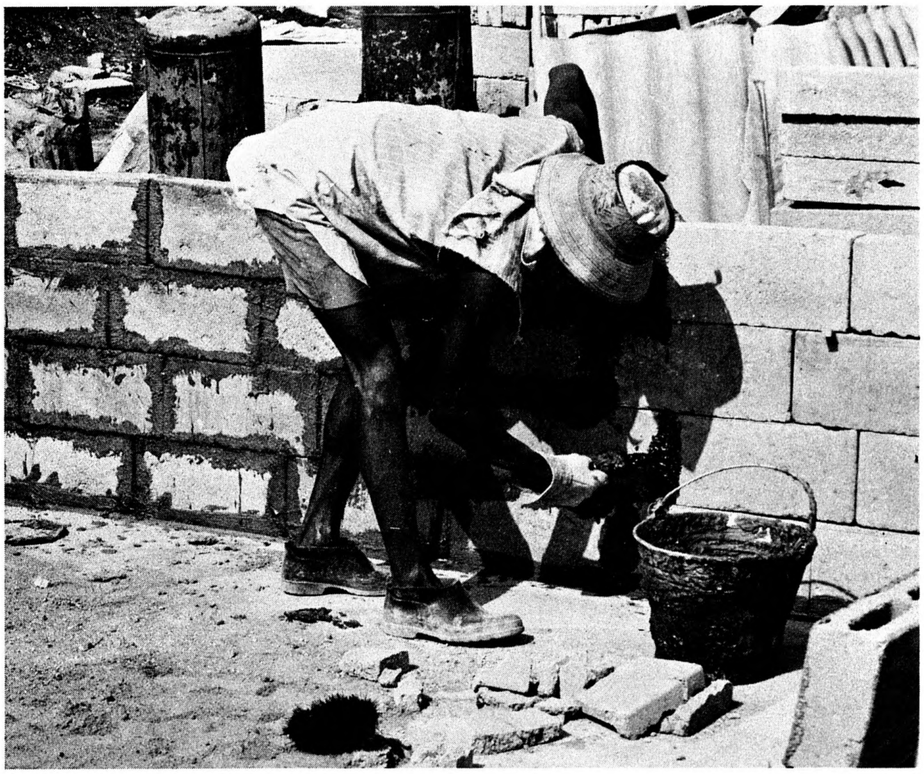


Figure 13. Painting Joints Only on One Wall Section

Figure 14. Prefabrication of a Lintel, Using the Formulation

Figure 15. The Mixture Dries Immediately, and the Lintel Can Be Lifted and Carried to the Location for Installation

Figure 16. The Prefabricated Lintel in Position

TECHNICAL ASPECTS OF SURFACE BONDING

by

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January 21, 1975

LIST OF FIGURES

TECHNICAL ASPECTS OF SURFACE BONDING

The surface bond technique for wall construction consists of stacking concrete blocks, or other building modules, into a wall without mortar being placed between the blocks. A bonding material is then applied to both surfaces of the wall to form a structural membrane against the blocks which waterproofs the wall and binds it into an integral unit. A number of materials have been evaluated as the bonding material, but this project has intentionally been limited to cement base coatings and sulphur base coatings.

In 1963 a small building, housing the shipping and receiving group, was built using a sulphur base coating at Southwest Research Institute[(1)*]. To date this building is still in excellent condition[(2)] and continued service is anticipated for many years to come. In 1969, under a United Nation's project[(3)] several walls were constructed in Guatemala employing concrete block as well as fired clay tile and these walls are still intact. To our knowledge these are the two oldest sites employing structures with the surface bonding technique and both used the sulphur coating. More recently in the United States other structures are appearing employing the surface bond technique, using both the cement base and sulphur base systems.

Construction Using Cement Base Coatings

When the walls are to be constructed on a concrete slab or beam the first layer of blocks is set in a cement mortar similar to regular

*See Bibliography

mortar construction, except that no mortar is placed between the blocks in the verticle joints as shown in Figure 1. This levels the first layer and bonds it to the slab. The blocks are then stacked one atop the other without any mortar between them to a convenient height as shown in Figure 2. Depending on the width and quality of the block this may vary from three or four blocks to the full wall height. The 10 cm wide blocks were stacked five high in this program. The block surfaces were then wetted with water to improve adhesion of the cement base coating which is then troweled onto the wall surfaces as in Figure 3. After one day the rest of the blocks were stacked and then coated as before. This type of construction is not recommended for more than single story units for both the cement and sulphur systems.

Construction Using Sulphur Base Coatings

Construction with the sulphur base coatings is very similar to that already described with the exception that the sulphur coating is applied hot in the molten stage. As seen in Figure 4, the first layer is bonded to the slab by pouring the sulphur into the cavity of the block. Adhesion was sufficient that when an attempt was made to remove one of the bonded blocks the concrete slab failed in tension before the sulphur bond between the block and slab failed as shown in Figure 5. Next, the blocks are stacked to a convenient height and the sulphur formulation is then painted onto the surface. Conventional paint brushes may be used, however, it was found that small brooms worked as well as the paint

Figure 1. Setting the First Row in Cement Mortar

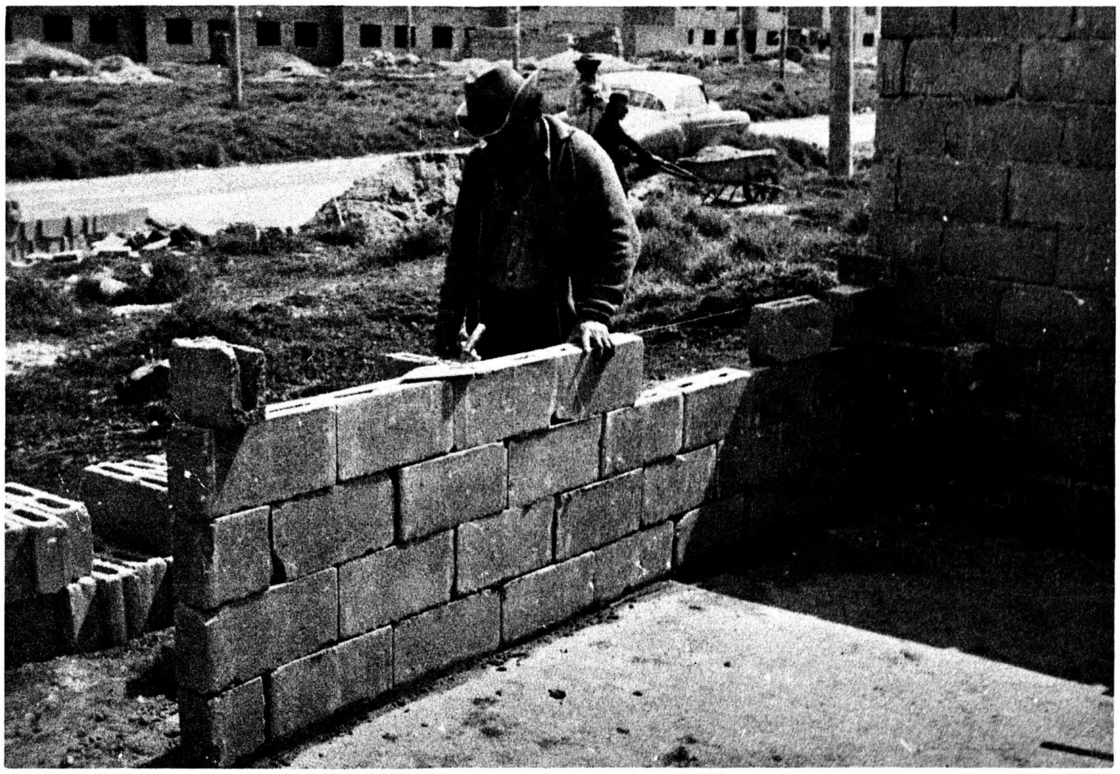

Figure 2. Stacking the Concrete Blocks Without Mortar Between Them

Figure 3. Applying the Cement Formulation to the Wall

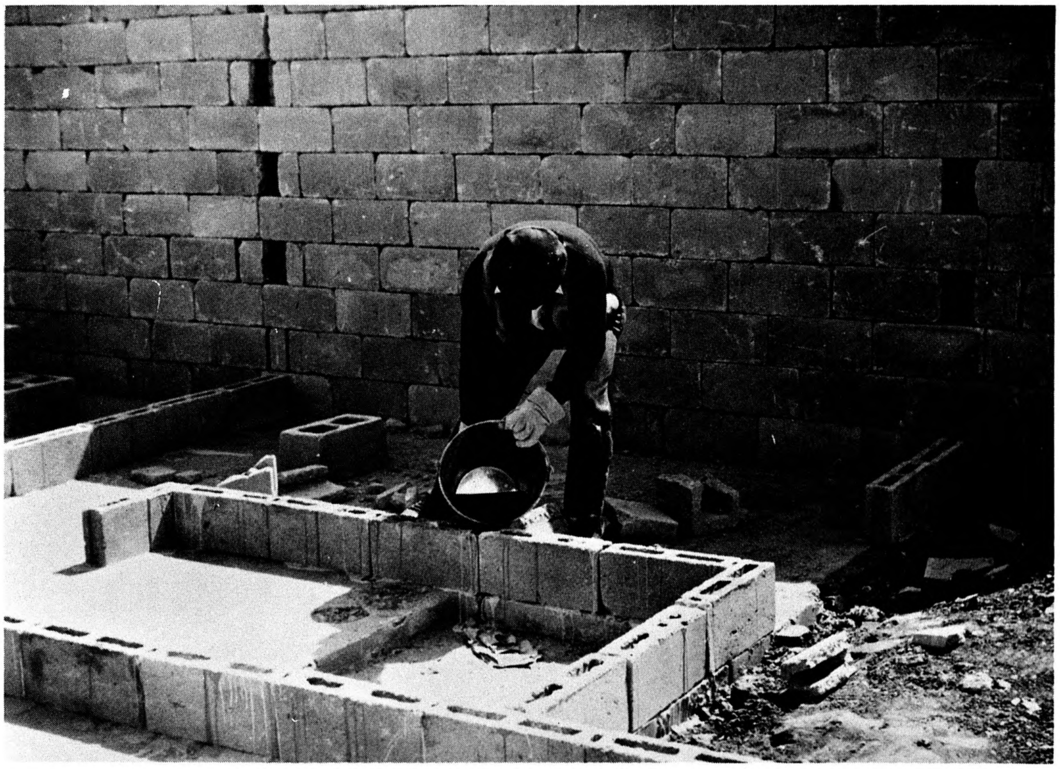

Figure 4. Bonding the First Row of Blocks With Sulphur

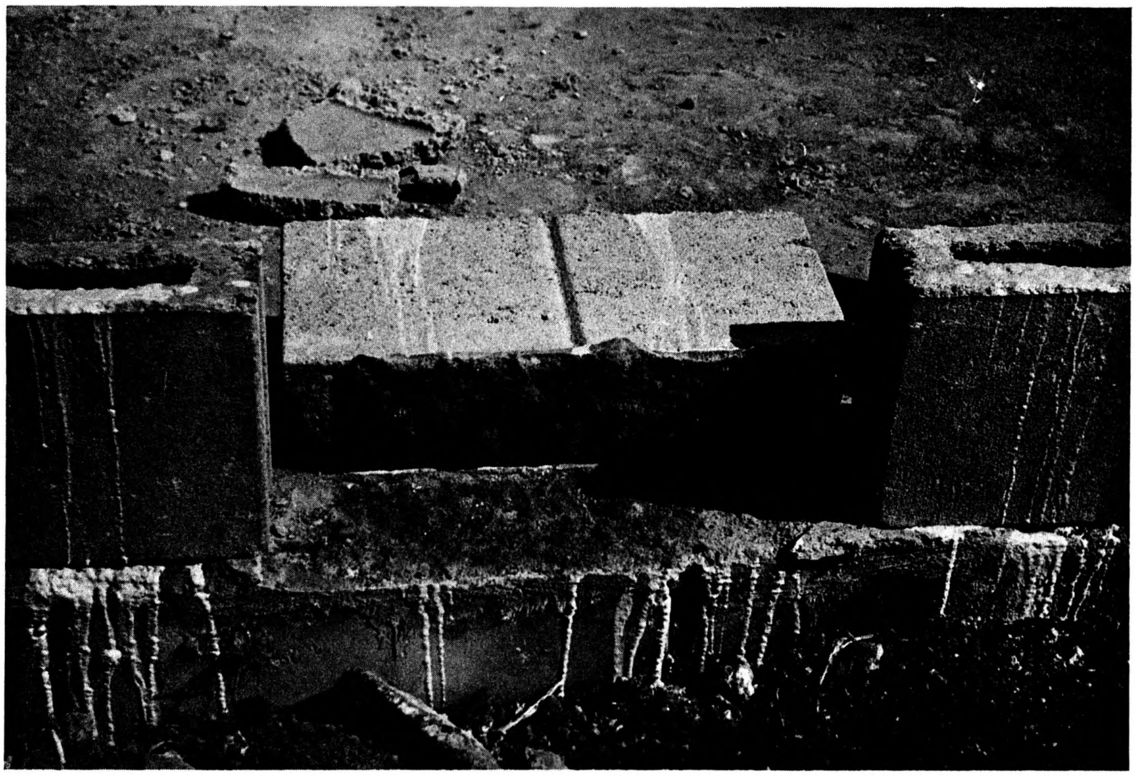

Figure 5. Bond of Block to Concrete Slab is Greater Than Tensile Strength of Slab

brushes and were considerably less costly.

The coating is applied to a thickness of 2 to 4 mm. At this thickness, the coating will solidify in 20-30 seconds. The entire wall surface can be coated with the sulphur formulation as in Figure 6, or only the joints can be painted as in Figure 7. The preferred method is to coat the entire wall surface since this gives a stronger and more waterproofed surface, however, painting only the joints requires less than half as much sulphur coating, thus being more economically attractive. If the wall is to be plastered eventually with conventional cement plaster, then painting only the joints allows for a considerably savings in cost and material.

With the sulphur base system, lintels can be prepared very quickly and easily on the job site. Concrete blocks are butted end to end, without mortar between the joints. The sulphur coating is applied, preferably to the entire surface, but the joints only can be coated if desired. Within 5 to 10 minutes, the lintels can be placed atop window or door openings as in Figure 8 and then coated in the same manner as blocks being added to the wall. The maximum span that can be bridged in this manner is determined principally by the flexural strength of the concrete block itself and should be determined on site using the blocks available. Two methods were used in improving the strength of the blocks. The first method was to fill the cavity of the blocks with the sulphur coating formulation. The formulation left over at the end of the day was used for this application, rather than dumping it on the

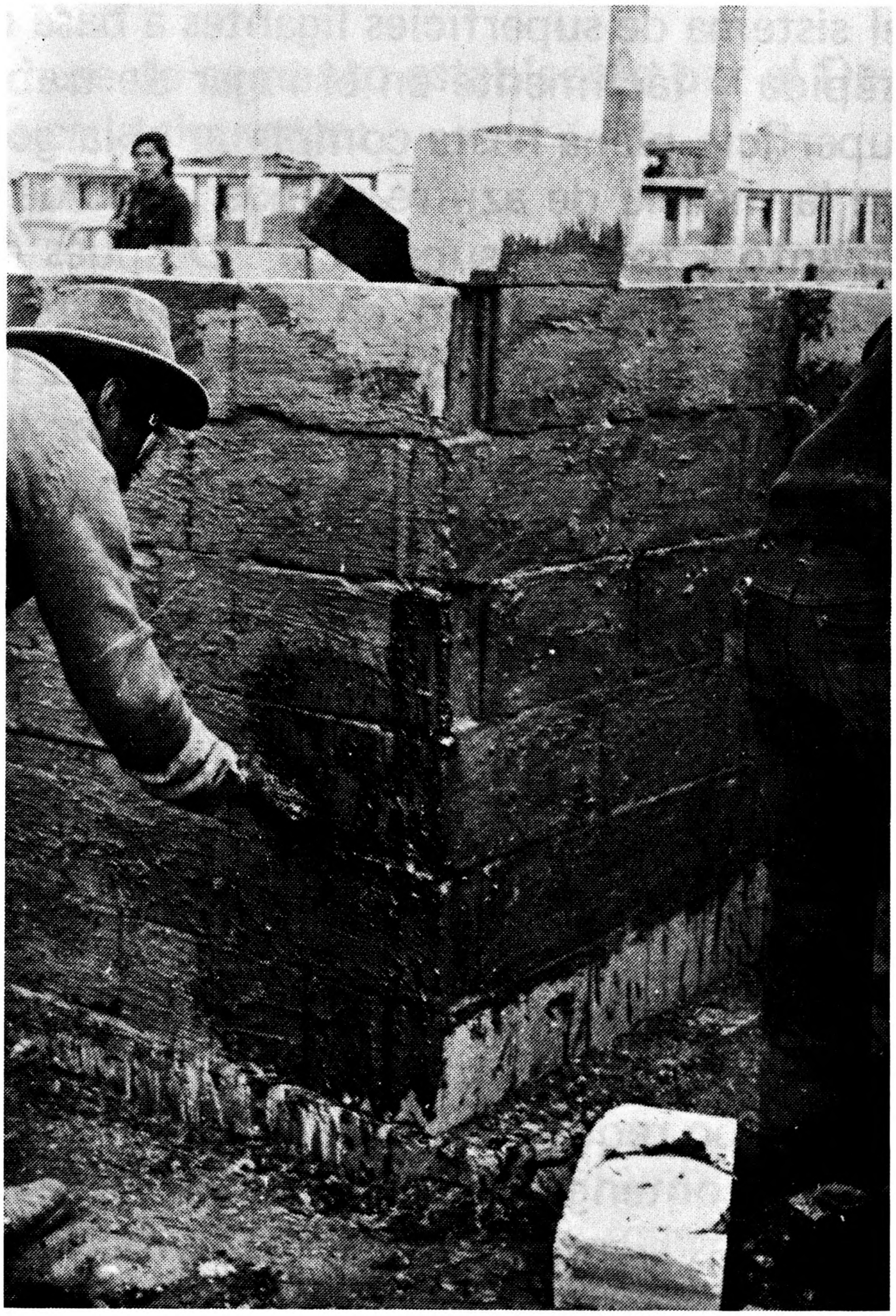

Figure 6. Painting the Sulphur Coating by Brush Over the Total Surface

Figure 7. Painting Only the Joints With the Sulphur Coating

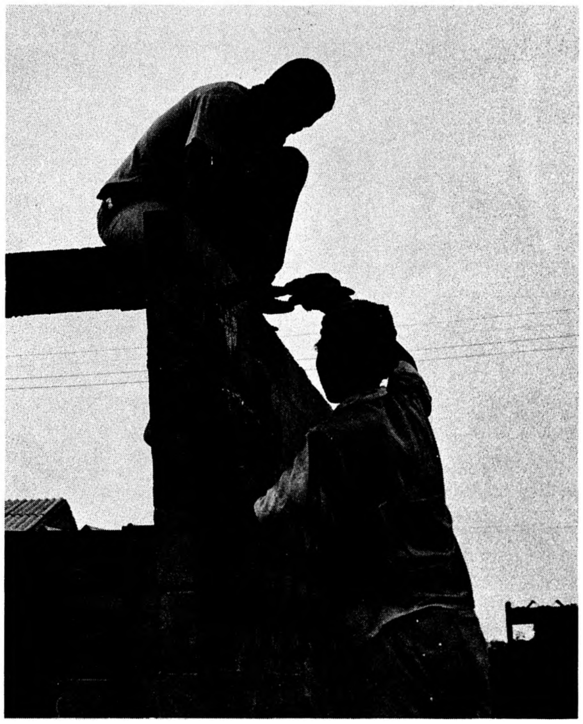

Figure 8. Setting a Pre-Made Lintel in Place

ground. The blocks prepared in this manner were thus made to fail through the center section of the block, rather than through the cavity section.

The second means of improving the strength of the concrete blocks was to submerge the blocks in molten sulphur, or the sulphur plasticized with dicyclopentadiene. The length of time required to saturate the block with the sulphur will depend on how wet the concrete block is. When the sulphur no longer bubbles due to the release of the moisture from the block, this is usually the indication that saturation is complete. With the relatively dry blocks that were used in Cartagena, this took from 30 minutes to 1 hour.

<u>Cement Coating Formulations and Equipment</u>

The cement coating developed by the United States Department of Agriculture has the following constituents in parts by weight:

100	cement
20	lime
5	glass fiber - 1/2" long
2.5	calcium chloride
1.25	calcium stearate

sufficient water to give a workable mix.

The lime gives better workability to the mix, the glass fibers give reinforcement, the calcium chloride accelerates the set, and the calcium stearate acts as a waterproofer. Essentially all that is required is the cement and a reinforcing fiber. A special alkali resistant glass fiber is the only glass fiber recommended with this formulation. The alkali resistant type glass was not available in Colombia, so the conventional type that was available, as well as asbestos fibers were returned to Southwest Research Institute where strength determinations were made in the laboratory. Two formulations were prepared, one using glass fibers, the second using asbestos fibers. The flexural strength was determined after the specimens cured for 6 days and this is reported in Table I.

Table I

Flexural Strength for Glass Fiber and Asbestos Fiber Reinforced Cement Coatings

Formulation (parts by weight)		Flexural Strength at 6 days psi (Kg/m^2)
100	cement	535 (376,000)
20	lime	
5	1/2" glass fibers	
1.25	calcium stearate	
Water		
100	cement	
20	lime	425 (299,000)
10	1/4" asbestos fibers	
1.25	calcium stearate	
Water		

Formulations were also made using the same amount of silica sand as cement in both of the formulations above and the strengths were the same as without the sand. In erecting small walls, there was no advantage to adding sand to the formulation. The sand added volume to the mix, but more was required to cover the same area and it was much more difficult to work than the formulation without the sand.

Wallettes (small walls) 4 ft x 4 ft (120 cm x 120 cm) were erected using 10 cm wide blocks with each of the formulations in Table I. In addition one wallet was erected using a commercially available coating mix. These will be evaluated over the next several years and can be seen in Figure 9.

The only equipment required for the cement coating is a mortar box for mixing the formulation, a hoe or shovel for mixing, and a trowel for applying the mix.

Sulphur Coating Formulations and Equipment

The sulphur coating formulations consist of sulphur, a plasticizer, and a reinforcing fiber. The preferred plasticizer for the sulphur coating is dicyclopentadiene. In addition to plasticizing the sulphur, the dicyclopentadiene imparts a fire retarding characteristic to the formulation. In all of our work to date, the dicyclopentadiene has been the most practical modifier, and is also the most economical. By far the most widely used fiber has been glass fiber, however, other fibers have been used, including asbestos.

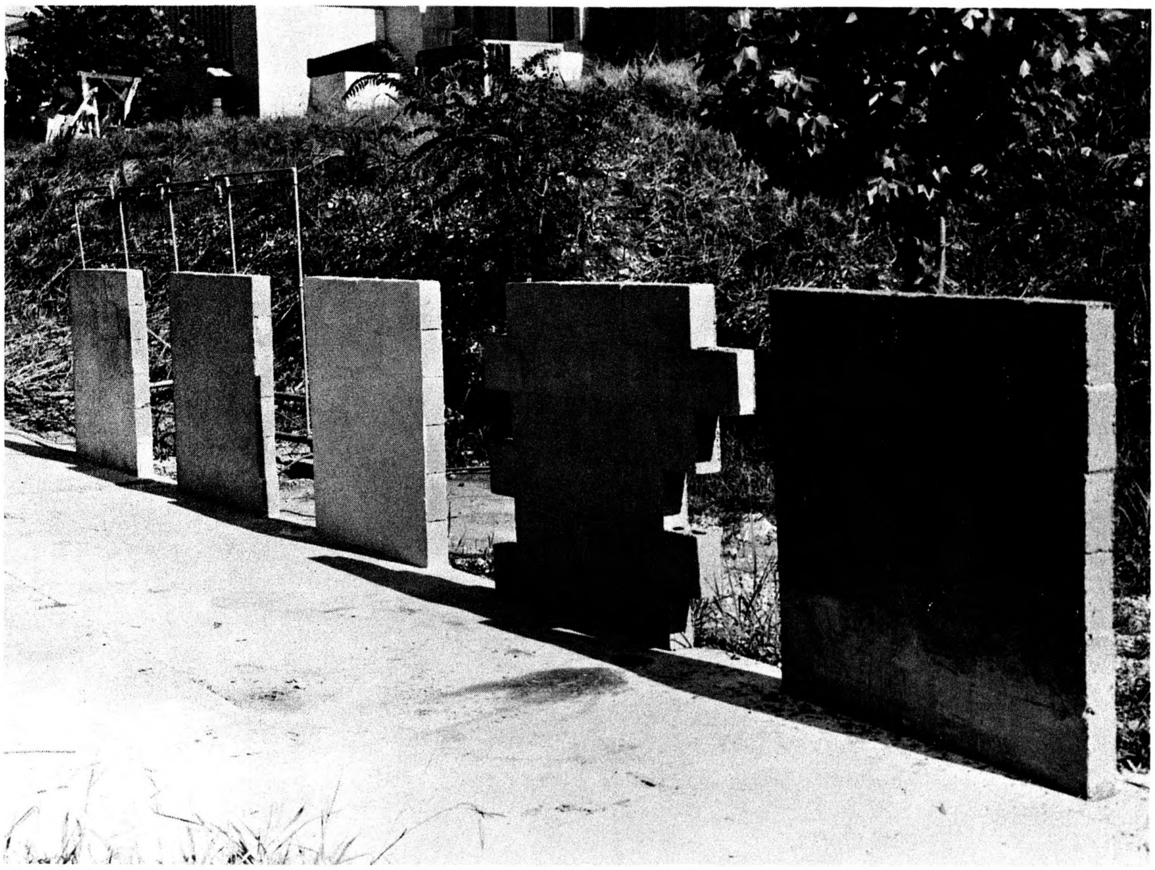

Figure 9. Wallettes Under Long Term Evaluations

On the initial visit to Bogota in February, 1974, samples of glass fiber, asbestos, talc and dicyclopentadiene were obtained and returned to Southwest Research Institute for further study.

The optimum formulation developed as a coating in the States that was designed specifically for spraying had the following formulation in parts by weight:

100	Sulphur
7.5	talc
3	milled glass fibers
3	dicyclopentadiene.

The talc suspends the glass fibers and inparts a thixotropic nature to the formulation to prevent its flow on a verticle wall. The milled glass fibers are in an almost powder-like form which allows for a sprayable formulation. On the subject program, it was anticipated that the coating would be applied with brushes and this allowed the investigation of larger fibers. Table II lists the flexural strengths of the various formulations.

The talc obtained in Colombia was not as finely ground as that normally used in the formulation, hence the need for 3 to 4 times as much as indicated in Table II. The fact that the formulation employing only 5 parts asbestos was considerably stronger than the cement coatings, indicated that this formulation should be adequate for construction. The last formulation in Table II was prepared using a floatation grade sulphur product which is approximately 70% sulphur with the impurity being fine

Table II

Flexural Strength for Glass Fiber and Asbestos Fiber Reinforced Sulphur Coatings

Formulation (parts by weight)		Flexural Strength at 1 day psi	(kg/m^2)
100	Sulphur	1475	(1,040,000)
7.5	Talc		
3	milled glass fiber		
3	dicyclopentadiene (DCPD)		
100	Sulphur	1465	(1,030,000)
7.5	Talc		
3	1/4" Colombian glass fiber		
3	DCPD		
100	Sulphur	1810	(1,275,000)
30	Talc (Colombian)		
3	1/4" Colombian glass fibers		
3	DCPD		
100	Sulphur	685	(482,000)
20	Talc (Colombian)		
1	1/4" Colombian glass fibers		
3	DCPD		
100	Sulphur	1430	(1,000,000)
20	asbestos (Colombian)		
3	DCPD		
100	Sulphur	1075	(755,000)
10	asbestos (Colombian)		
3	DCPD		
100	Sulphur	710	(500,000)
5	asbestos (Colombian)		
3	DCPD		
100	Sulphur (floatation ore 70%S)	1325	(931,000)
5	asbestos		
3	DCPD		

volcanic ash. Unfortunately samples were not obtained of this material until the houses were constructed, however, the strength tests indicated that it will work fine and considerable savings should be realized since it is half the cost of the pure elemental sulphur.

The basic sulphur formulation employed in all three of the houses in Colombia was as follows, although some minor modifications with the asbestos type were made at times.

100 sulphur

5 asbestos

3 DCPD

One wallette employing glass fiber and one employing asbestos fiber were constructed at SwRI as shown in Figure 9 for future evaluations over the years.

For melting the sulphur, any available heat source may be used including wood, coal, or gas. Bottled propane gas was used on the subject program and is highly desirable because of the control by regulating the flame. The quantity used varied from 35 to 50 kilos per house depending on the size of the house. A commercial burner may be used, although we had burners fabricated from metal conduit as shown in Figure 10. Any convenient size metal tank may be used for melting the sulphur. For demonstration purposes a 5 gallon bucket is shown in Figure 10. For actual construction, two 55 gallon drums were used. To help insulate and hold the heat, concrete blocks were stacked around the tanks. Approximated 250 kilos of sulphur were melted in each tank at one time.

Figure 10. Propane Burner and Tank
Used for Melting Sulphur

For speeding the melting of the sulphur one technique is to place only 20-25 kilos of solid sulphur in the drum. As soon as all of this is melted, additional solid sulphur is added, making sure that the sulphur stays liquid. If all of the sulphur is added initially, it will take much longer to melt the sulphur because solid sulphur is a very poor heat conductor. By melting in the manner described, the 250 kilos were usually melted and the temperature raised to 145°C within 1 1/2 to 2 hours. Once the sulphur temperature is at 145°C, the dicyclopentadiene is added and allowed to react for 15-20 minutes before the asbestos is finally added. Caution should be taken that the temperature does not exceed 150°C, or the quantity of dicyclopentadiene does not exceed 3 parts per 100 parts of sulphur, else the dicyclopentadiene can overreact with the sulphur to form a very viscuous, rubber-like material that must be discarded.

The asbestos usually contains water so that there will be bubbling and foaming when it is first added to the molten mix. Once the foaming has stopped and the temperature of the mix is 145-150°C, the material is ready to be applied.

The recommended safety equipment for personnel applying the sulphur mixture is long sleeves to prevent burns if sulphur is splattered on the arms, gloves to protect the hands, and goggles or glasses to protect the eyes. It should always be remembered that molten sulphur is at a temperature above that of boiling water, but at 150°C, is usually well below that of asphalts as currently used for roofs and roadway repairs.

Construction of Houses

Two houses were constructed in Bogota in Barrio Garces Navas. These were single story units of approximately $50M^2$ of floor area. The walls were 10 blocks high plus the mortar joints. Due to elimination of the mortar joints using the surface bond technique, the walls were built 11 blocks high which was approximately 1/2 block higher than the conventional wall.

One house was built with the cement-asbestos coating and the second house was built with the sulphur-asbestos formulation. Using a crew of two masons and two helpers, it took 2 1/2 days to construct the walls on each house, which is comparable to what is required on the conventional houses. With practice, the crews would become more proficient and could possibly construct them in less time.

An overall view of the cement coated and sulphur coated houses in Bogota is shown in Figure 11. The front of the sulphur coated house is partially painted with white paint in the photograph. Figure 12 is a closeup of the sulphur coated house after the entire front of the house has been painted with white paint to give the appearance of white plaster.

One problem encountered in the Bogota construction was the time required to stack the blocks into a plumb wall. This problem was solved in the Cartagena construction by using precut wooden wedges as shown previously in Figure 7. This saved considerable time. The second problem involved large cracks in some joints as in Figure 13. These required

Figure 11. Overall View of Cement Coated and Sulphur Coated Houses in Bogota

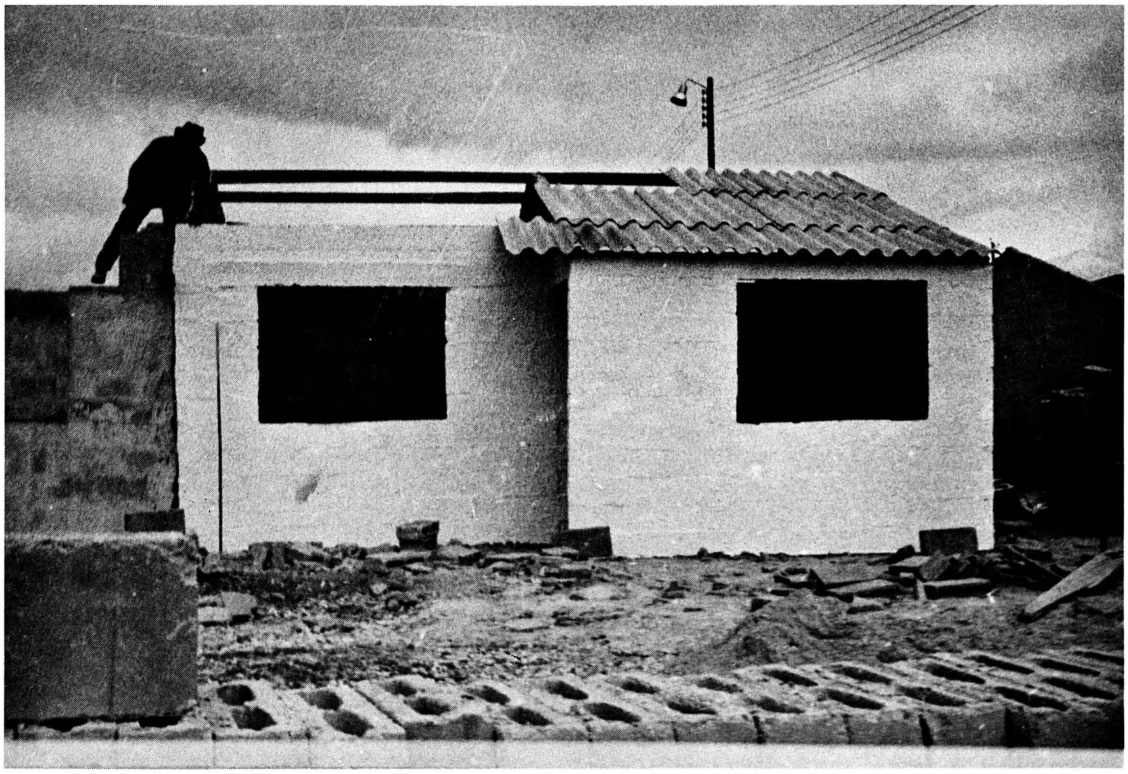

Figure 12. Close-Up of Sulphur Coated House After Being Painted With White Paint

Figure 13. Large Cracks Between Blocks

excess material and considerable time to fill. It was found that by stuffing paper or other filler material in the large cracks first, and then painting over this with the sulphur, this problem was eliminated.

The two houses constructed in Cartagena in Barrio Chile were approximately $70M^2$ in floor area. On the conventional houses, atop the 10th row on these houses a steel reinforced poured-in-place concrete beam was used to tie all of the walls together because of a very unstable soil in the Cartagena area. By using the surface bond technique this beam was eliminated, thus saving considerable time and cost. A crew of three masons and two helpers was used in Cartagena. One of the helpers melted the sulphur and mixed the formulation. These houses took 5 days to construct the walls, but the same crew was used to complete the walls. In the conventional construction, a separate crew was used for constructing the beam. In order to save costs, one house had only the joints painted, as opposed to the second house that was coated over the total block surface as in Bogota. As anticipated, approximately half as much coating material was required when only the joints were painted. Figure 14 is an overall view of the two houses in Cartagena.

In order to speed construction using the sulphur system, spraying the coating as in Figure 15 would be very desirable. A small pump (Figure 16) was purchased in Bogota and returned to SwRI where experiments were conducted using this pump to spray a sulphur coating. The only modification required of the pump was a change in the seals. The use of such a pump would allow for either spraying or coating over the entire block surface or

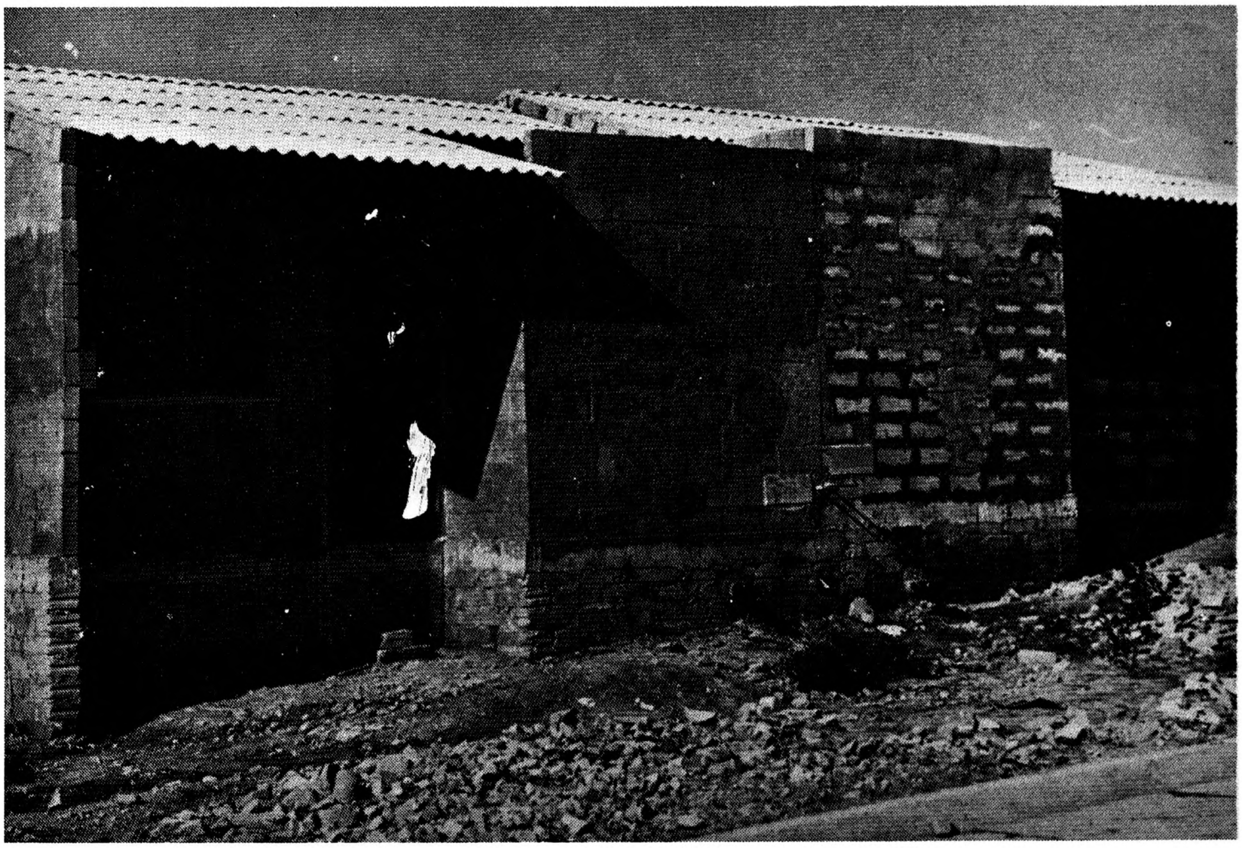

Figure 14. Overall View of Houses Constructed in Cartagena

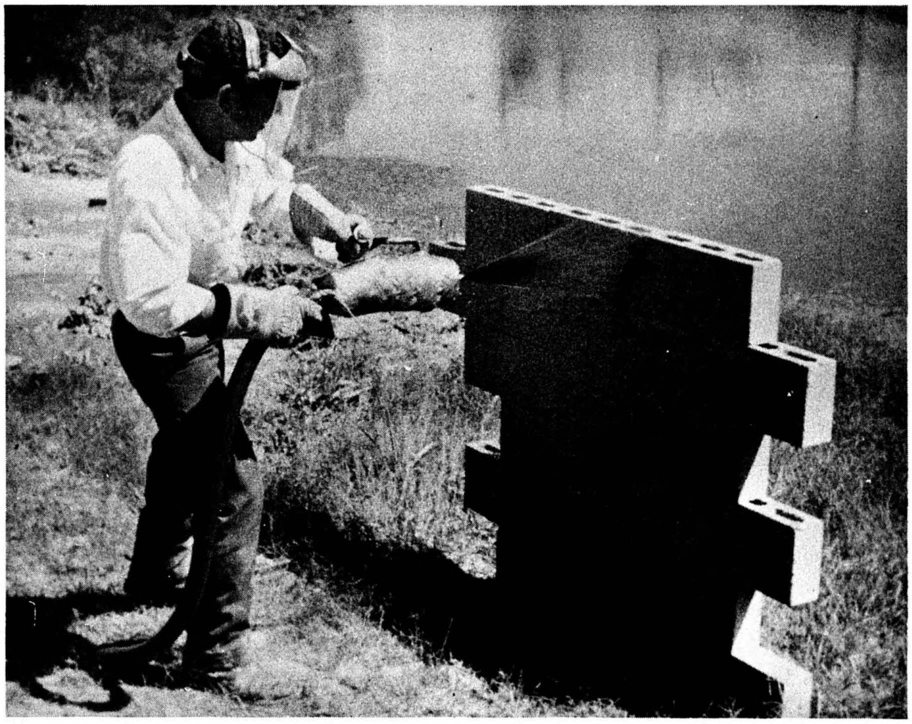

Figure 15. Spraying the Sulphur Formulation

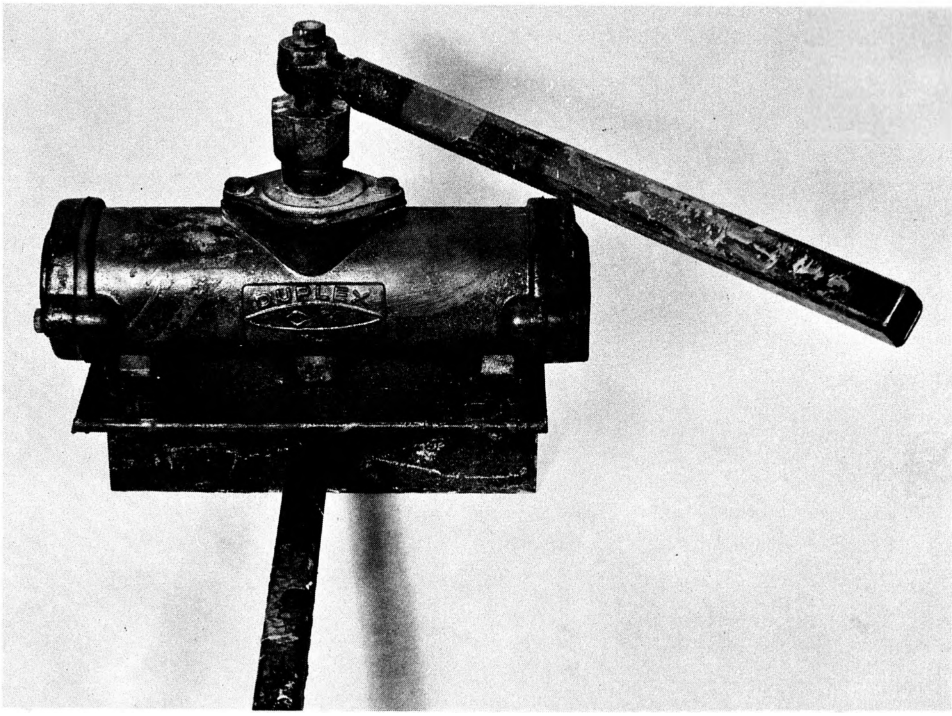

Figure 16. Small Pump Used to Spray
Sulphur in Laboratory Tests

controlling the width of the stream for coating only the joints.

From the results thus far obtained in Colombia, the surface bond technique appears competitive with conventional mortar construction and depending on specific house designs, can offer considerable economic savings.

The labor force is highly capable of adapting this technique to meet local needs. On the first four houses constructed by Colombian crews, the time of construction was very comparable to that of conventional mortar construction. The materials costs in most instances could be competitive with cement mortar, and in the houses in Cartagena, considerable material costs were realized. Further refinements in both materials and techniques should encourage more widespread use of this technique.

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THE FIRE RISK IN LOW COST HOUSING

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THE FIRE RISK IN LOW COST HOUSING

Southwest Research Institute, under a contract for the Office of Science and Technology of the United States Agency for International Development, has been conducting research on the utilization of the surface bond construction technique for low cost housing applications. By this technique the walls are constructed by stacking concrete or other type blocks without any mortar between them and then applying a coating containing a fibrous material on both the exterior and interior of the walls. The coating inparts tensile strength to the walls, seals the walls, and results in not only lower cost walls but walls that are physically superior to conventional mortared walls. Work on this project has led to the construction of four houses in Colombia demonstrating this concept. One house was constructed using a cement and asbestos fiber coating. The other three houses were constructed using a modified sulphur-asbestos fiber coating. The sulphur was modified by the addition of dicyclopentadiene which acts as both a plasticizer and fire retardant for the sulphur.

The fact that sulphur burns has been known a very long time. Homer (about 900 B.C.) tells of its fumigating properties when burned to sulphur dioxide. Sulphur is referred to in the Bible as "Brimstone" or "The Stone That Burns". The public is aware of this and has every right to be concerned over flammability of construction materials. By the same token, no one associated with this development has any intention of subjecting anyone in any country to any undue risks, or hazards. The purpose of this paper is to attempt to place the problem of fire risks in low cost housing in its proper frame of perspective, so that those who are concerned can understand the parameters involved and thereby be more knowledgeable as to the nature of the risks involved.

Figure 1 shows a cross section of a typical low cost house as constructed in many countries of the world. Basically, it consists of a slab floor, with block walls and wooden rafters supporting a roof. In a hypothetical situation where a fire occurs within such a structure, consider the hazards in terms of the different types of building materials used or proposed for use in low cost housing. If an ignition source produces a fire in the center of such a house, with the passage of time the walls and the roof structure will experience a temperature rise as depicted in Figure 2. The block walls of low cost housing which have great mass, exhibit a heat-sink effect; that is they absorb heat more readily than a typical roof structure which is less massive. It is, therefore, probable that the roof materials will experience a temperature rise faster than the upper walls. As the temperature inside the building rises consider what happens to some of the typical building materials and systems.

Table 1 is a summary of some of the physical properties of typical materials used in low cost housing, such as masonry or adobe block materials, wood, thermoplastics and the sulphur based material being

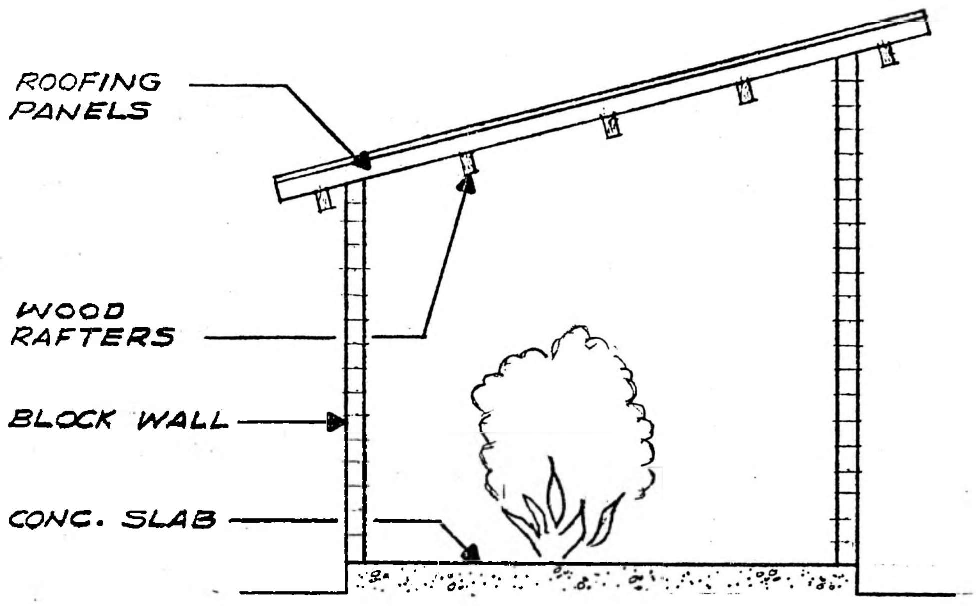

FIGURE 1.

CROSS SECTION OF TYPICAL LOW COST HOUSE

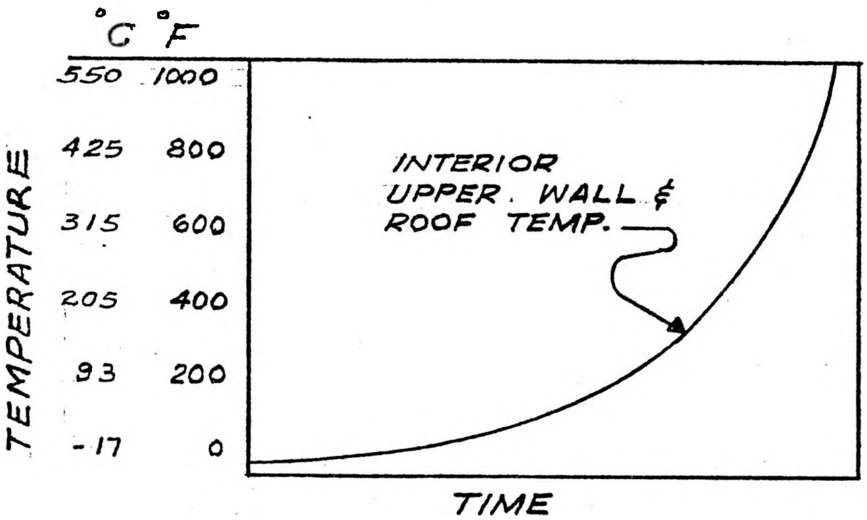

FIGURE 2.

TIME-TEMPERATURE RELATIONSHIPS THAT OCCUR IN A BUILDING THAT IS EXPERIENCING AN INTERNAL FIRE.

Table 1 Properties of Building Materials as Related to Combustion and Fire

Property	Blocks (Concrete Adobe)	Wood	Thermoplastics (Asphalt, etc.)	Sulphur Based Material
Softening Point °C	-	-	93	-
°F	-	-	200	-
Melting Point °C	-	-	176	120
°F	-	-	350	246
Pilot Ignition °C	-	288	300-500	175
°F	-	550	570-930	350
Heat of Combustion BTU/Lb	-	7,000-8,000	12,000-16,000	4,000
Cal. Gr./Gr.	-	3,900-4,400	6,600- 8,900	2,200
Smoke Generation	No	Yes	Yes	No
Toxic Fumes	No	Yes	Yes	Yes

considered for use. It is apparent that as the temperature increases in a wall made of typical concrete or adobe block, the block material wall element does not have a softening point, a melting point, an ignition temperature, a smoke generation problem or a toxic fume problem. From the standpoint of fire protection, block materials are ideal building materials. The first building material problem that might be encountered due to fire would very likely be with some of the presently used and contemplated roofing materials. Thermoplastic composition as employed in roofing systems, such as asphalt, have a softening point around 93°C/200°F. This means that at this temperature they will begin to soften and lose their structural integrity. Around this temperature one can envision the possibility of the roofing material or any other part of the house made from these materials as falling into the room. If there were humans present they could be subject to massive skin contact burns or possible injury from falling debris.

As the temperature continues to rise, the next material that would suffer distress would be the sulphur coating if the surface bond construction technique utilizing sulphur as a binder were used to coat the block walls. Sulphur does not soften. It melts at 120°C/246°F, and if pure elemental sulphur were used as the binder one would envision the sulphur wall coating as melting and portions of it flowing down the walls. The sulphur based coating developed for the surface bond construction technique will melt on the surface but because of the additives it does not flow down the wall.

While this would lessen the structural integrity of the building, one would not expect the building to fail to support the roof because the walls are largely self supportive. The next occurrence that might be expected with increasing temperature would be for any thermoplastic material in the building to reach its melting point at which time it would be a mobile liquid and flow readily. With further temperature rise we would expect to encounter the ignition of combustible materials. Wood, thermoplastics and sulphur based materials have pilot ignition points in the range of 176°C/350°C to 570°C/930°F. The exact point of pilot ignition can vary widely for the same material depending upon the conditions. Once ignited there is a great variance in their burning intensity and in their subsequent contribution to the conflagration. Sulphur has a heat of combustion of 4,000 btu's per lb, whereas wood has a heat combustion of 7-8,000 btu's per lb and thermoplastics have a heat of combustion of 12-16,000 btu's per lb. Thus, wood contributes twice and thermoplastics three to four times the amount of heat that sulphur does on combustion. This heat has the effect of raising the temperatures of surrounding materials and bringing them to their ignition point, which propagates the fire both in area and intensity.

The sulphur composition employed in the surface bond construction technique contains a fire retardant material that forms an intumesent char on the surface on the sulphur which retards the underlying sulphur from being ignited and burned. Thermoplastic materials and wood would be expected to continue to burn. As the wooden rafters burned and lost their strength, the entire roof structure would collapse. In many of the low cost housing systems the roofs are tile, transite or sod and falling heavy debris would constitute a major personnel hazard.

Now, consider the aspect of fire and combustion products as a risk to personnel safety. Approximately 60°C/140°F is about the maximum temperature that can be tolerated by the human skin. Any temperature above this burns human flesh. This occurs in an open space fire before any building materials or building element systems are affected. The next probable measure of risk in a fire situation is that of smoke generation. Wood contributes heavily to smoke generation as do thermoplastics, particularly the aromatic compounds contained therein which form dense black smoke. Sulphur based materials do not normally generate smoke, in that sulphur dioxide, the main product of combustion of sulphur, is a colorless gas.

Another serious personnel aspect of combustion is the toxicity of the gases produced. Man is accustomed to breathing air--nothing else. In the case of wood, thermoplastics and sulphur, all produce toxic products of combustion. The degree of toxicity of these materials varies. It is interesting to consider the fact that most people who die from smoking in bed actually lose consciousness from breathing the fumes from the combustion of the mattress and have often succumbed before ever receiving any flesh burns. Dr. Donald Dressler, Professor of Surgery at the Harvard Medical School, has recently been studying fire related deaths.[(1)] Now that the treatment for burn victims has so greatly improved, and so many more patients survive the first day, they are now able to observe trauma of a type heretofore unappreciated. In the study of large numbers of patients who have been in fires, they have observed that on the second day after the fire and after having succeeded in returning the individual's bodily signs to near normal conditions, the individual dies inexplainably. Through smoke tunnel tests using both large and small animals, Dr. Dressler and his associates have been able to identify that the smoke from white pine and certain other woods contain constituents that are responsible for these deaths. White pine is considered ideal window trim and sash material, wall paneling, etc. and is used extensively in houses constructed in the United States and elsewhere.

The product of sulphur combustion is sulphur dioxide. This is highly irritating to the eyes, nose, throat and lungs in concentrations greater than 6 to 20 (parts per million) by volume. At 150 ppm, the irritation is almost unbearable. Concentrations in excess of 550 ppm result in suffocation. Exposure to sulphur dioxide has no permanent systemic effect, and indeed forces evacuation of the premises without causing permanent damage to an individual's health. This is most significant, since the typical low cost house resident is seldom, if ever, more than 10 meters (33 ft.) from a door or window exit. It should be remembered that we are not considering or contemplating the construction of high rise or multi-story buildings; all building spaces are at grade level. One might even consider putting sulphur in mattresses to awaken those who have fallen asleep and force their evacuation. One would not expect an individual in a house with sulphur dioxide fumes to linger there very long. By the same token the slow burning rate of sulphur and the fume generation in a small enclosure such as that of the low cost house would alert an individual of impending danger and allow ample opportunity to escape. There are certain individuals whose respitory systems are very sensitive to any variation of what they breathe and are subject to a "shut-off" of the breathing process. It is very difficult to predict this effect or provide protection against it.

The United States is considered one of the more advanced countries in the world in terms of building codes. These building codes vary in requirements and content from one another according to geographical locale, political entity and actual physical location. There is a wide variation of materials allowed from one situation to another according to building type, building use and building siting. Most of the codes rely on the use of American Society of Testing Materials standard tests that have been developed over the years. Even with this elaborate system of ASTM tests and building code requirements it is possible for materials to pass these tests; be accepted under the building codes, be placed in buildings and, in the case of fire, cause major injuries and death.

The history of urethane foams is a case in point. Urethane foam materials that had passed the ASTM test and code restrictions have been responsible over the past several years for numerous deaths in the United States. This has necessitated the imposition of restrictions on their use.

In the past, sulphur based coatings have actually passed some of the principal ASTM fire tests, as reported on in a paper by A.C. Ludwig and the author entitled "Fire-Retarding Elemental Sulphur".[2] But one is hesitant to rely totally on these findings. Thus, we must seek to be responsive to the protection of an individual in a structure and not rely entirely on the ASTM tests or the building code requirements.

Many countries where low cost housing is being constructed have no building codes, test procedures or facilities to evaluate materials behavior. At this point, science and technology might contribute solutions to these problems. In looking into this, one finds that the "state-of-the-art" worldwide is less than might be hoped for. A vivid example of this shortcoming was the occurrence at Cape Kennedy in Florida several years ago when three United States astronauts perished when fire broke out in their space capsule. Immediately after this event great emphasis was placed on the subject of fire retarding of materials. Much of this work was carried out at the United States National Aeronautics and Space Administration's Ames Research Center in Mountainview, California.[3] After intensive studies at Ames, it was found that virtually any material could be successively fire retarded by use of various quantities of different chemical compounds, namely the halogens such as chlorine, fluorine and bromine. The drawback, however, is that when heavily fire retardant materials are heated they may liberate extremely toxic gases, and people succumb to the toxic gases as quickly, if not more quickly, than to the fire itself. One of the leading scientists at Ames contributed his life in this very manner. After several demonstrations, where he held a torch to a piece of fire retarded material, he experienced a heart attack which was later directly connected with the inhalation of the "off-gases". A material can be "fire retarded" but it should be remembered that if heated to a high enough temperature, virtually all materials that are oxidizable, especially those containing carbon, sulphur and similar elements, will liberate as a gas these elements or compounds. When this occurs, the materials are prone to enter into very basic chemical reactions where electrons are exchanged and products of oxidization are formed. It is very difficult, if not impossible to prevent this type of reaction from taking place.

In the case of sulphur, there are specific steps that can be taken to lessen the risks of using it as a binder material in low cost housing. In addition to using the recommended 3 percent by weight of dicyclopentadiene which acts as a fire retardant material for sulphur, the incorporation of filler material such as sand, talc or volcanic ash with the sulphur will further retard the burning characteristics. In many developing countries there are native elemental sulphur deposits of volcanic or sedimentary origin that contain quantities of the associated inert minerals and these materials are ideally suited for use in the surface bond construction technique. The presence of these inert minerals in the native sulphur deposits disqualifies them for the world sulphur market, which adds justification for their use locally. The fewer small protuberances there are on the surface of a sulphur base coating the more difficult it becomes to ignite the coating. Such protuberances may be reduced by improving the skill and method of application. Using less sulphur coating by painting the joints or using thinner coatings will also greatly lessen the problem. Finally, a finish coating of some low cost inorganic material such as white wash (quick lime and water) will further retard the sulphur coatings tendency to burn.

In an effort to simulate the fire hazards of the sulphur surface bond technique in a real life situation and compare it to other materials a series of experiments were devised. One major source of fire in dwellings occurs in cooking, when grease or cooking oil is inadvertently overheated and ignited. Therefore, as a fire source a cast iron skillet with 100 grams of cooking oil was placed on a hot plate and intentionally overheated until ignition occurred. When placed directly against a 4 ft. (122 cm) x 4 ft. (122 cm) wallette made from 1/4 in. (0.62 cm) thick plywood, ignition of the plywood occurred one minute after ignition of the cooking oil. Ten minutes after ignition of the cooking oil the plywood wall had been consumed from the bottom to the top and there was nothing left to test. The ceiling and side walls would have been consumed had they not been made of cement asbestos board due to the heat intensity of the burning wall.

Figure 3 is a photograph of the same experiment conducted against a wallette made from concrete blocks joined by a 2.0 in. (.61cm) wide external application of the sulphur base coating over only the joints.

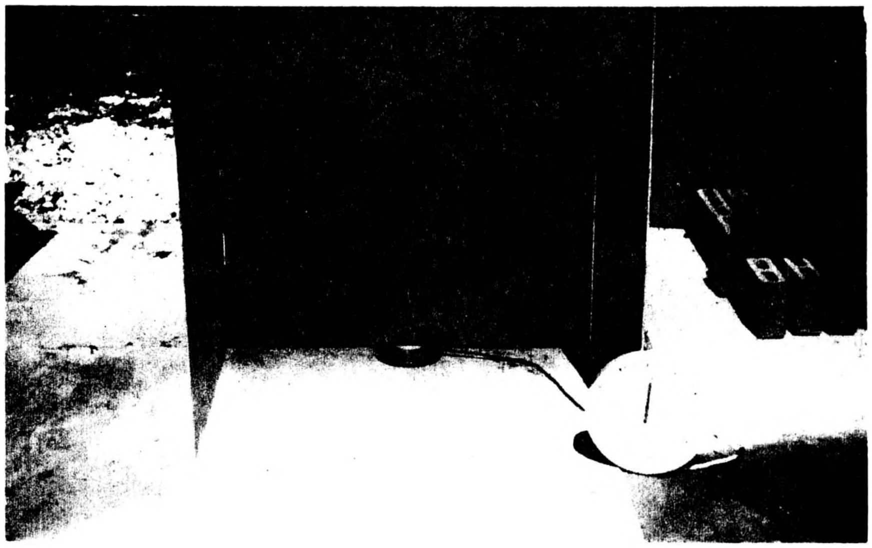

FIGURE 3 FIRE TESTING OF A WALLETTE

Three minutes after ignition of the cooking oil the sulphur base coating over the joints exposed to the flame ignited. After eight minutes the cooking oil in the skillet had burned to completion and the fire in the skillet went out. Fifty minutes later, after progressing only up to the second row of blocks the sulphur base coating extinguished of its own accord. The sulphur base coating burns very slowly and as it burns it forms an intunescent char that prevents the underlying material from burning and thus the bond between the blocks is maintained. To show that the bond is maintained the wallette was layed over horizontally with the burned face down and supported on each side as a beam. It was then loaded on the top center with 525 pounds (238 kilos) of blocks and it did not break. This is equivalent to a unit load of 64.8 $lbs/ft.^2$ (315 Kgs/sq. meter). The wallette thusly loaded is shown in Figure 4.

FIGURE 4 JOINT COATED WALL TESTED AS A BEAM

The unit load on a wall subject to a 100 mile/hour (160 Kilometer/hour) wind is approximately 30 $lbs/ft.^2$ (146 Kgs/sq. meter).

A third wallette was constructed with concrete blocks using the sulphur base coating over the entire surface. After exposure to the same fire source the coating self-extinguished after one hour and seventeen minutes, with surface charing extending all the way to the top of the wall. At no time did the ceiling or walls exceed 140°F(60°C). The sulphur base coating on the back side of the wall was unaffected. This wall was also treated as a beam as shown in Figure 5 and it also supported a load of 525 pounds (238 kilos) without failure, and thus like the joint coated wall maintained its structural integrity well in excess of design requirements.

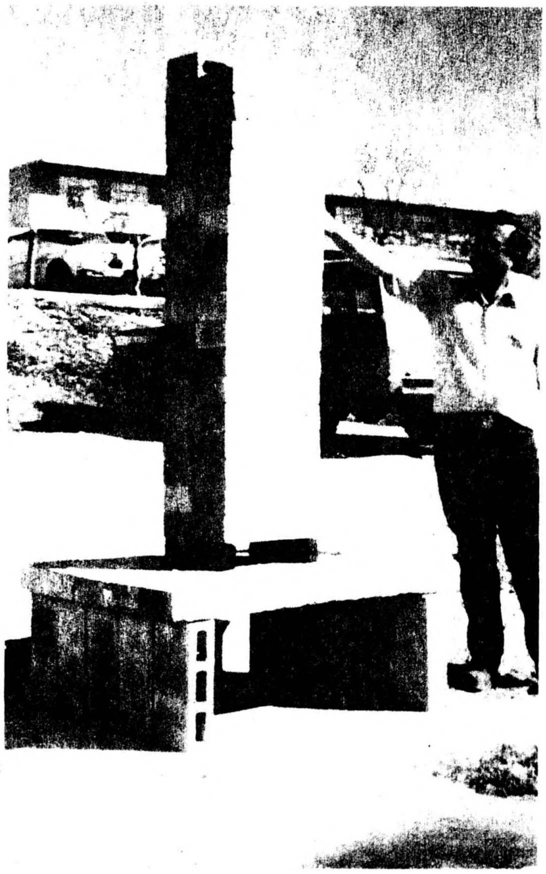

FIGURE 5 TOTALLY COATED WALL TESTED AS A BEAM

A sulphur fire in an enclosed structure can be smothered by closing all entrances and denying it air. Barring this, a sulphur fire should preferrably be extinguished with water. If, for any reason, water cannot be used, burning sulphur can be extinguished by covering it with dirt, sand or other inert material (National Safety Council Data Sheet 492).[4]

Thus, while there are risks in living in a typical low cost house, these risks are not nearly as great as one might be led to believe. If weighed against the risks of no shelter and exposure to the elements they are minor. In the final analysis these risks are certainly less than the risks inherent in living in the average house that one finds in the developed countries. Fortunately, utilization of the surface bond construction technique does not rest merely on the use of sulphur; cement and other non-combustible binders can be employed. Sulphur should only be used by those who have weighed all of the factors and understand what is involved.

REFERENCES

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SURFACE BONDING PROJECT FROM THE POINT OF VIEW OF AID MISSION IN COLOMBIA

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The present project under direct financial assistance of AID/ Washington, was very well received by both the private and the public sectors in Colombia. However, such a project, at an experimental level, has not as yet determined the doubts that might arise if techniques were to be applied on a large scale. We would therefore like to ennumerate in this report the different variables that should be considered before implementing the technique on a national level. It would be wise perhaps to individually outline the points of view of both thepublic and the private sectors, inasmuch as a few variables are only relevant to one of them.

Point of View of the Private Sector

As we are all aware, the financial aspect is the only incentive that would encourage the private sector to change its construction techniques. In other words, if results from the preliminary stage of a project such as the one presented in this Conference, will show that considerable savings in costs are obtained, perhaps the constructor might take the risks that a change of technique involves.

The first phase of the project consisted in the construction of four houses in Colombia. As a result, it was found that savings in costs were obtained from the houses constructed in Cartagena, while a small increase in costs was observed in those constructed in Bogota.

The most important cost reduction in Cartagena was through savings obtained in the construction of the beam. Under the conventional technique the construction of the beam was necessary, operation that required considerable time and high costs. Under the new proposed technique, the beam can be constructed with the same blocks used on the walls, but coated with sulphur. There is no reduction in strength and therefore the technique is acceptable. However, we undertand that there are similar construction in Colombia in which the beam has not been considered essential, this without representing exaggerated risks for the constructor responsible. If this is the case, savings obtained in Cartagena are not worthwhile. We believe that this aspect should be studied carefully by the constructor who might at any time be interested in using this technique.

However, it should be clearly emphasized that estimate costs presented herein are only valid for Colombia. In some other countries where costs of conventional constructions are rather high, the surface bonding technique results in larger savings.

Coutries where cement industry is very poor, or lacking completely, and are incurring in large investments to acquire the cement, should contemplate the possibility of a change in technology such as to that which is presented in this conference. Moreover, if a country under a similar situation as mentioned above, supplies the necessary sulphur, the perspective should appear highly attractive.

At the present time, in our discussion implicit has remained the fact that the technique as such has been completely considered satisfactory. Tests made in Bogota and Cartagena are a clear evidence. Although a few persons seem to be concerned about aspects such as flammability of the sulphur coat, conduit installations and other similar problems, it seems to us that these can be easily solved and that they do not involve major risks as compared with problems arisen in the conventional construction. Therefore, we would like to assume that the sulphur surface bonding technique with minor modifications and improvements would possibly be suitable for the construction of residential units.

Point of View of the Public Sector

Independently of the costs that the new technique may involve for the private sector, the government should carefully analyze the effects on the economy as a whole. Aspects such as availability of sulphur, dicyclopentadiene, glass fibers and propane, must be evaluated not only from the standpoint of costs to the constructor but specifically its advantages for the country.

As previously mentioned, for countries using at present other construction techniques and for which foreign holdings are being spent for acquisition of the necessary materials, the problem is rather simple. It only requires to compare import costs of the new materials with the former and find out whether this represents any savings. Furthermore, if some of the new materials are locally available the technique would become even more attractive.

On the other hand, if common construction techniques are not requiring the use of foreign holdings, but the use of new materials does, attention should be given upon comparing the opportune cost of the holdings (generally much higher than the current exchange in the developing countries) with the savings that the new technique might produce.

It should be also mentioned that the use of sulphur surface bonding in the developing countries will require imports of at least ohe of the materials. This is the dicyclopentadiene, a proceedings from oil which very few producers are obtaining throughout the world. Nevertheless, the amount of this product used is rather small; therefore no large amount of holdings is required.

Thus, it is evident that for countries having large amounts of sulphur available or those who have relatively poor construction industry, techniques presented herein,as an alternative,must be carefully analyzed in order to determine its feasibility. An important aspect to be considered is the fact that this technique does not require the development of highly expensive and complicated factories such as those for cement production. In this technique the production is done at the construction site; of course all scale economies are lost but facing the lack of resources this might become a short term solution.